ADA120845

REPORT DRXTH-IS-CR- 82157

BZ DISPOSAL FACILITY
DEVELOPMENT AND DESIGN

TASK 4
INCINERATION OF PYROTECHNIC MUNITIONS
IN A DEACTIVATION FURNACE

Dale W. Folsom

BATTELLE
COLUMBUS LABORATORIES
505 KING AVENUE
COLUMBUS, OHIO 43201

JULY 1982

FINAL TEST REPORT

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Prepared for:

U.S. ARMY TOXIC AND HAZARDOUS MATERIALS AGENCY
ABERDEEN PROVING GROUND, MARYLAND 21010

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SECURITY CLASSIFICATION OF THIS PAGE *(When Data Entered)*

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER DRXTH-IS-CR- 82157	2. GOVT ACCESSION NO. ADA130 8/5	3. RECIPIENT'S CATALOG NUMBER
4. TITLE *(and Subtitle)* BZ DISPOSAL FACILITY DEVELOPMENT AND DESIGN: Task 4, Incineration of Pyrotechnic Munitions in a Deactivation Furnace		5. TYPE OF REPORT & PERIOD COVERED Final Test Report
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Dale W. Folsom		8. CONTRACT OR GRANT NUMBER(s) DAAK11-81-C-0080
9. PERFORMING ORGANIZATION NAME AND ADDRESS Battelle Columbus Laboratories 505 King Avenue Columbus, Ohio 43201		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS U.S. Army Toxic and Hazardous Materials Agency Aberdeen Proving Ground, Maryland 21010		12. REPORT DATE July, 1982
		13. NUMBER OF PAGES
14. MONITORING AGENCY NAME & ADDRESS*(If different from Controlling Office)*		15. SECURITY CLASS. *(of this report)* Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT *(of this Report)*

Distribution unlimited. Cleared for public release.

17. DISTRIBUTION STATEMENT *(of the abstract entered in Block 20, if different from Report)*

18. SUPPLEMENTARY NOTES

19. KEY WORDS *(Continue on reverse side if necessary and identify by block number)*

Incineration	Retort	Burn Time
Pyrotechnic	Deactivation Furnace	
M18 Smoke Grenade	Pollution Control	
APE 1236 Furnace	BZ Demilitarization	
	Residence Time	

20. ABSTRACT *(Continue on reverse side if necessary and identify by block number)*

M18 smoke grenades were incinerated in an APE 1236 furnace to obtain information on the heat released from the grenades, furnace operation, the amount of pollutants generated and the performance of a venturi scrubber in controlling the emissions. The tests were conducted to obtain data which could be utilized by the Chemical Agent Demilitarization Program. The tests were conducted at the Pine Bluff Arsenal Incineration Complex which consisted of an APE 1236 furnace, afterburner, quench, water-based venturi scrubber, ID fan and stack. The heat released from the grenades when fed at eight per minute into the furnace—

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(equivalent to the projected disposal rate of BZ munitions) resulted in localized excessive skin temperatures in the insulated retort sections. It is believed that removal of the insulation would reduce the skin temperature to acceptable levels. The particulate loading measured downstream of the quench was 0.008 grains per dscf (corrected to 12 percent CO_2); the gaseous emissions averaged 276 ppm of SO_2, 52 ppm of HCl, 6 ppm of Cl_2 and 41 ppm NO_x at a flue gas flowrate of 5488 dscfm. Twenty-one percent of the sulfur contained in the grenades was detected at the outlet of the quench. These levels are below the State of Arkansas air emission standards. The venturi scrubber at a 20 inch water pressure drop removed 56 percent of the particulates but was ineffective in reducing gaseous emissions.

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SUMMARY

Tests were conducted at the Incineration Complex at Pine Bluff Arsenal, Arkansas to obtain information to be used in the design of the full scale incineration and pollution control system for the BZ demilitarization facility. The thrust of the tests was to secure data on 1) the effect on the furnace of processing pyrotechnic munitions at rates simulating that proposed for the BZ deactivation furnace, 2) the quantity and characteristics of pollutants generated from the incineration process and 3) the performance of a venturi scrubber in controlling particulate emissions. The tests were performed using M18 smoke grenades as simulants for the BZ munitions. The M18 grenades were chosen because the pyrotechnic fill in the grenades most closely resembles that in the BZ munitions, and the grenades are expected to exhibit behavioral characteristics similar to the BZ munitions in a thermal environment.

The Incineration Complex test equipment consisted of an APE 1236 rotary retort deactivation furnace, horizontally oriented afterburner, water quench, variable throat venturi scrubber, induced-draft fan and stack. This equipment has a configuration similar to that currently proposed for the BZ demilitarization facility.

Initial tests have been conducted with grenades soaked in a solution of water with a surfactant (Avirol III). Tests feeding one grenade at a time into the deactivation furnace indicated that the grenades burned rapidly and smoothly (18 to 51 seconds) without evidence of violent behavior. These burn times were shorter by a factor of about 2 than that for normally functioned grenades (grenades ignited by a fuze at normal ambient temperatures). The burn time was not reduced by longer heatup of the grenade before ignition in the deactivation furnace as would be expected due to the pyromix being at a higher temperature at the time of ignition.

The pyrotechnic mixture contains substantial quantities of inorganic salts that leave a char residue which remain in the munition canister after incineration. The grenades from these tests were checked for evidence of molten char, as severe corrosion would result in the deactivation furnace if molten char is produced and flows out of the munition canister. From past tests (Ref. 1) where a differential thermal analysis was performed on char from incinerated M18 smoke grenades a melting point was indicated at 950 F. There was no evidence of molten char in the grenade canisters

after incineration even at furnace operating temperatures of 1200 F and char temperatures of up to 1150 F.

The furnace performance and emission tests were conducted feeding eight M18 smoke grenades per minute (the equivalent of the proposed feed rate of two M138 BZ bombs per minute, the targeted BZ disposal rate) into the deactivation furnace. Despite the high feed rate of the grenades, the quantity of furnace infiltration air was sufficient to prevent leakage of smoke from the furnace openings. It was observed that the third and fourth retort sections attained comparitively high skin temperatures. The high localized temperatures were attributed to the insulation installed on the surfaces of the two sections rather than a heat overload to the furnace. Calculations suggest that skin temperatures would be normalized if the insulation was removed.

The measured particulate loadings after the afterburner and quench for these tests of 0.008 grains per dscf emitted from the eight smoke grenades per minute (corrected to 12 percent carbon dioxide) was well below the Arkansas State Regulation of 0.2 grains per dscf at 12 percent CO_2. The majority of the particulate was submicron in size. The venturi scrubber proved moderately effective for reducing particulate loading at the tested conditions. The reduction of particulate was enhanced by an increase in pressure drop across the venturi from 14 inches of water to 20 inches of water resulting in an increased removal efficiency of 38 to 56 percent.

The gaseous emissions measured at the afterburner averaged 411 ppm of SO_2, 52 ppm of HCl, 6 ppm of Cl_2 and 41 ppm of NO_x at a flue gas flowrate of 5488 dscfm.

In conclusion the Incineration Complex at Pine Bluff Arsenal was demonstrated to be very effective for the disposal of M18 smoke grenades.

To the extent that M18 grenades serve as simulants of BZ munitions, the following implications relative to the BZ incineration facility may be made.

- The configuration of the equipment in the test incineration complex proved effective in disposing of pyrotechnic munitions with minimal emissions
- Only 31 percent of the sulfur contained in the grenades fed into the deactivation furnace was detected at the outlet of the quench

- The particulate and SO_2 emission anticipated from the proposed BZ facility, based on the test observations, will be less than the levels for which a scrubbing system is required to meet State of Arkansas air pollution standards

- Although some char was discharged into the retort from the grenade canisters during incineration, the lack of evidence of molten char in the grenades at the 1200 F furnace temperatures indicates that the corrosion problem in the deactivation furnace may not be severe

- The heat losses from the retort surface and to the infiltration air entering the deactivation furnace are sufficient to maintain furnace temperatures at acceptable levels

- The flowrate of infiltration air to the deactivation furnace will have to be greater than the gas generation rate of the incinerated munitions to prevent agent BZ from being discharged from the deactivation furnace.

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INCINERATION OF PYROTECHNIC MUNITIONS
IN A DEACTIVATION FURNACE

Contract DAAK11-81-C-0080

to

UNITED STATES ARMY
Toxic and Hazardous Materials Agency
July, 1982

BATTELLE
Columbus Laboratories

1. INTRODUCTION

The tests described in this report were conducted to resolve knowledge gaps concerning a) the effect of incinerating BZ munitions in a deactivation furnace, b) the amounts of gas and particulates generated and their chemical compositions and c) the effectiveness of a venturi scrubber in removal of the particulates generated at the targeted BZ demilitarization/disposal rate.

Interest in obtaining this information arises from a current program within the U.S. Army Toxic and Hazardous Materials Agency (USATHAMA) for demilitarizing pyrotechnic munitions containing agent BZ. Stringent restrictions on experimental activities (to prevent possible release of agent BZ) and on the transport of munitions containing BZ makes tests with actual BZ-containing munitions difficult. Therefore, the tests were made using M18 smoke grenades, a munition that contains a pyrotechnic mix similar to that in the BZ munitions and organic dyes in place of the chemical agent BZ. The M18 smoke grenades were considered to be a reasonable (and safe) simulant for BZ munitions.

BZ munitions are filled with a press loaded charge containing 50 percent agent BZ, 23 percent potassium chlorate, 18 percent sodium bicarbonate, and 9 percent sulfur. The M18 smoke grenades used for these tests were filled with a press loaded charge containing 40 percent volatile dyes, 27 percent potassium chlorate, 22.6 percent sodium bicarbonate, and 10.4 percent sulfur. Thus, the compositions are similar, and a basic similarity in behavior has been demonstrated (Ref 2). There are known differences in the quantitative behavior of the two mixes, the BZ pyromix is more sensitive to impact and appears to burn approximately 4 times faster than that of the smoke mix, even though the calculated heat of reaction for the smoke mix is slightly higher than that of the BZ pyromix.

The tests described in this report were conducted at the Incineration Complex at Pine Bluff Arsenal (PBA), Pine Bluff, Arkansas. The equipment of the incineration complex consisted of an APE 1236 rotary retort deactivation furnace, horizontally oriented afterburner, water quench, variable throat venturi scrubber, induced-draft fan and stack. The tests involved the cooperative efforts of personnel from USATHAMA, U.S. Army Environmental Hygiene Agency (USAEHA), PBA, Midwest Research Institute (MRI), and Battelle Columbus Laboratories (BCL). Responsibilities of the various groups were as follows.

PBA - Prepare and operate the test facility. Provide smoke grenades and required safety equipment.

USAEHA - Provide equipment and supervisor for sampling the inlet duct to the scrubber and the stack for particulate matter and gas compositon.

USATHAMA - Make arrangements for and coordinate the overall test program.

MRI - Evaluate interferences and/or operating problems caused by operation of a prototype BZ alarm, sampling the furnace exhaust.

BCL - Prepare final test plan, determine modification required to carry out tests, provide equipment and personnel to monitor the furnace stack for SO_x, provide general engineering support during the tests, and prepare a report describing the tests and the test results.

The tests were performed during the period of November 30 - December 9, 1981.

2. OBJECTIVES

The objectives of the tests were as follows.

1. Determine the operating temperature and residence time in the deactivation furnace with respect to completion of volatilization without exceeding the char melting point, and reduce fuel usage and gas flow to the afterburner.

2. Determine the effect of a feed rate of eight grenades per minute on the control of the deactivation furnace temperature.

3. Determine the composition, mass, and size of particulates generated by the incineration of grenades in the deactivation furnace system.

4. Determine the effectiveness of the venturi scrubber in controlling emissions from grenade incineration.

5. Determine gaseous emissions from the afterburner.

The Test Plan is Appendix I.

3. TECHNICAL BACKGROUND

Of primary concern in the design of a deactivation furnace for BZ munitions is the rate at which the munitions burn and release gas, as the gas evolution rate will determine the required gas handling capacity of the following afterburner. In an extreme case, where the reaction is fast, the munition may explode and require the incinerator to be designed to withstand the pressures generated by the explosion.

The munitions containing BZ, and similarly the M18 smoke grenades used in these tests are designed as internal burning munitions: that is, the pyromix is ignited in a core hole, and the generated gases are vented through the core hole while the reaction front advances radially through the charge. Specific reaction rates typically increase with increasing temperature of the reacting material and with the ambient pressure in the reaction zone. The actual rate of gas generation depends on both the specific reaction rate and the area of the reaction front.

When the BZ and smoke munitions ignite and burn in a normal mode, ignited by the fuze at ambient temperatures, the reaction front advances radially outward through the ambient temperature pyromix from the internal surface of the core hole. Thus, the area of the reaction front tends to increase progressively in a more or less controlled fashion. The gases are vented out of the ends of the core hole, thus, the pressure rise accompanying the reaction is moderate. When ignited in an incinerator, two possible differences from this sequence can be identified.

1. The pyromix may be preheated in the hot environment before ignition occurs.
2. Ignition may (and likely will) occur at the interface between the pyromix and munition case, rather than in the core hole.

Either of these conditions would be expected to lead to an increase in the mass reaction rate and gas generation rate. Preheating the pyromix should increase the specific reaction rate. Ignition of the pyromix at the pyromix-case wall interface will cause an increase in the reaction front area either by eventually causing burning to occur on both the exterior and interior (core hole) surfaces, or by breaking up the

pyromix charge (thereby dramatically increasing the surface area that can burn) as the generated gases attempt to escape from the unvented reaction zone. The increased gas generation rate, in any of these cases, would cause the internal pressure to increase and cause an additional increase in the mass reaction rate. In extreme cases, it might be possible that the internal pressure would rise to the point where the munition case ruptures.

The incineration temperature must be sufficient to completely volatilize the agent contained in the pyromix. However, pyrotechnic mixtures typically contain substantial quantities of inorganic salts, and these salts may be expected to leave a residue after the pyromix has reacted. Should this residue be molten at the incineration temperature, or at the temperature of a following decontamination furnace, high-rate corrosion of the furnace might occur as evidenced by test results reported in Ref. 3. Resolution of these issues and determination of the fuel usage constitutes the first listed objective.

BZ munitions and M18 smoke grenades have essentially the same pyromix composition. This mixture has a high heating value, which will contribute heat to the furnace as they function during processing. In the conceptual process plan, the target processing rate of 24 M44s per day results in an average feed rate of 8.4 M6 canisters per minute (i.e., at 10 oz. fill each, 84 oz/min of BZ-pyromix) and the processing of 12 M43s per day results in an average feed rate of 7.6 M7 canisters per minute (i.e., at 12 oz. fill each, 92 oz/min of BZ-pyromix). An M18 smoke grenade contains approximately the same amount of pyromix (11.5 oz.) as an M6 or M7 BZ canister. For the purpose of the tests for Objectives 2 through 5, a feed rate of eight M18s per minute (four every 30 seconds) was selected to simulate the feed of 2 M138s per minute (each M138 contains 4 M7s). The resulting heat released from the functioning canisters will have an effect on the control of the temperature in the deactivation furnace. Determination of this effect is the second objective.

In an incineration process for demilitarizing BZ munitions, it is intended that the BZ be destroyed by combustion. Although the dyes used in smoke grenades are unlikely to be good simulants for BZ, they will provide a conservative estimate of the afterburner's effectiveness for destroying BZ organics because the organic dyes are harder to combust due the their higher aromatic nature. Aromatics have a higher ignition temperature and are known to burn slower.

Deactivation furnaces such as the APE 1236 which was used in these tests, are known to emit heavy metals such as Hg, Pb, Zr, Ba, Sb, and Ti when these metals are present in the munitions being processed. Some of these heavy metals are present as components of the fuze in the BZ munitions and the M18 smoke grenades. Pb and Zn also are present as components of the M18 case. Emissions of such heavy metals is environmentally undesirable. Hence, it is necessary to know whether the quantities emitted are sufficient to require specific control measures. These points are addressed in the third listed objective.

The conceptual process plan calls for a pollution control system to reduce and control process emissions, and to prevent the release of any agent that may not be destroyed in the afterburner. The proposed pollution control system will contain a variable throat venturi scrubber, which is the same piece of equipment that is used at the incineration complex. A venturi scrubber with an appropriate scrubbing solution can control gaseous emissions and particulate emissions. The effectiveness of a venturi is a function of the pressure drop across it. The fourth listed objective is to determine the scrubber effectiveness in controlling emissions.

To complete the information needed for the design of a pollution control system the composition of the gaseous emissions must be determined. The fifth listed objective addresses itself to this point.

4. MATERIALS, EQUIPMENT AND INSTRUMENTATION

4.1 M18 SMOKE GRENADES

The M18 smoke grenades used in these tests were received in wood crates with each grenade packed separately in a fiberboard tube. Figure 1 illustrates the grenades, one of which has been defuzed, and the fiberboard tube.

The grenades used for Objective 1 tests were filled with Green IV smoke mix. For Objectives 2 through 5 the tests were performed with a mixture of grenades containing the Green IV, Yellow VI, Red III, and Violet IV smoke mixes. The nominal compositions of the smoke mixes are listed in Table 1.

The green smoke mix was chosen for the tests for Objective 1 due to its better simulation of BZ/pyromix. The logic for this selection was explained in Reference 1 and is included as part of Appendix II. The mixture of smoke mixes was
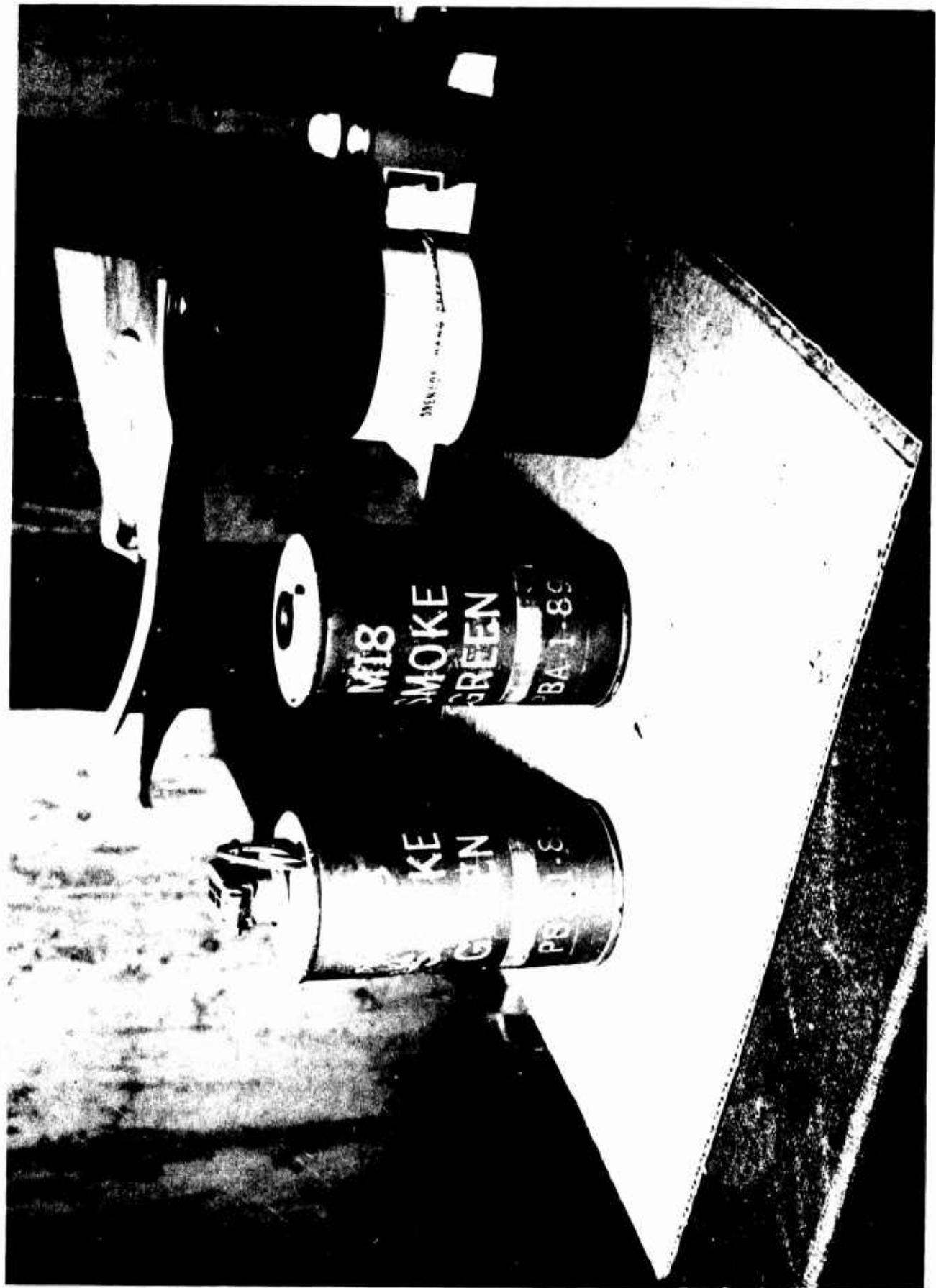
FIGURE 1. M18 SMOKE GRENADE AND FIBERBOARD CONTAINER

TABLE 1. COLORED SMOKE FILLINGS

Type mixture	Ingredient	Percentage (approximate)
Red smoke	Dye: 1-N-Methylaminoanthraquinone 85 percent; dextrin 15 percent	42
	Sodium bicarbonate	19
	Potassium chlorate	28
	Sulfur	11
Green smoke	1,4-di-p-toluidinoanthraquinone 70 percent; Indanthrene golden yellow 10.5 percent; Benzanthrone 19.5 percent	40.0
	Sodium bicarbonate	22.6
	Potassium chlorate	27.0
	Sulfur	10.4
Yellow smoke	Benzanthrone 65 percent; Indanthrene Golden yellow 35 percent	38.5
	Sodium bicarbonate	33.0
	Potassium chlorate	20.0
	Sulfur	8.5
Violet smoke	1,4-diamino-2,3-dihydroanthraquinone 80 percent; 1-N-Methyl aminoanthraquinone 20 percent	42.0
	Sodium bicarbonate	18.0
	Potassium chlorate	28.8
	Sulfur	11.2
Starter	Potassium nitrate	37.8
	Silicon	28.0
	Charcoal	4.2
	Cellulose nitrate	1.2
	Acetone	28.8

used for the tests of Objectives 2 through 5 due to insufficient quantities of any single color. Calculated combustion characteristics of the grenades are also given in Appendix II.

4.2 APE 1236 FURNACE

The tests were conducted in an APE 1236 furnace equipped with a pollution control system. The furnace, shown in Figure 2 with the burner located at the right, consists of four retort sections, each 5 feet long and 31.5 inches I.D. Figure 3 is a drawing of a typical retort section. As the retort is rotated, auger flights with a pitch of 2.5 ft. move items through the furnace countercurrent to the combustion gases. It was not feasible to synchronize the grenade feed with the rotational position of the retort barrel so that the grenades would move without stopping from the feed tube into the auger inlet. Consequently, some of the grenades were arrested in their movement at the inlet to the retort for up to a full rotation of the barrel. The furnace rotation speed was varied between 1 and 6 rpm for Objective 1, resulting in a residence time of 1.3 minutes to 8.7 minutes, and set at 1.8 rpm for Objectives 2 through 5, resulting in an average residence time of 5 minutes.

The furnace was fired with a modulating Hauck burner. The firing rate was controlled by a thermocouple which monitored the burner temperature. The controller modulated from a high firing rate to a low firing rate of approximately 9 scfm to approximately 25 scfm of natural gas. Figure 4 is a photograph of the natural gas burner and the discharge conveyor.

4.3 POLLUTION CONTROL SYSTEM

The pollution control system at the PBA Incineration Complex, consisting of an afterburner, quench, variable throat venturi scrubber, induced-draft (ID) fan and stack, are shown in Figure 5. The large duct in the lower left portion of the photograph conducts flue gas from the furnace into the side of the afterburner (the large white vessel). The quench is the tall black vessel in the center of the illustration. The venturi scrubber is hidden behind the separater and the duct to the ID fan.

FIGURE 2. APE 1236 DEACTIVATION FURNACE

Drill 47/64 Ream 3/4 (typ)

40.500 ± .020 BC

2-1/4 ± 1/4 wall

13 ± 1/4

10 ± 1/4

1-5/8 diam, 15 holes 20° apart (both ends)

40.500 ±.020 BC

36 ± 1/4

50 ± 1/16

Section B-B

15(typ)

30 (typ)

3 ± 1/16

30 (typ)

60 ± 1/4

Section C-C

4" 10" 13" 13" 10" 4"

Bearing point   Bearing point

15°

1-1/4 (typ)

1-1/4 (typ)

Section A-A

Note 1:
Lead of spirals is 30" uniformly on their periphery. A transition from 10" to 13" in height is made in the first 180° to mate with other increments. Perform this transition on one end only.

Note 2:
Two retort sections shall be same as shown except that the spiral shall begin at a height of 4" and increase uniformly to a height of 10" over the length of section.
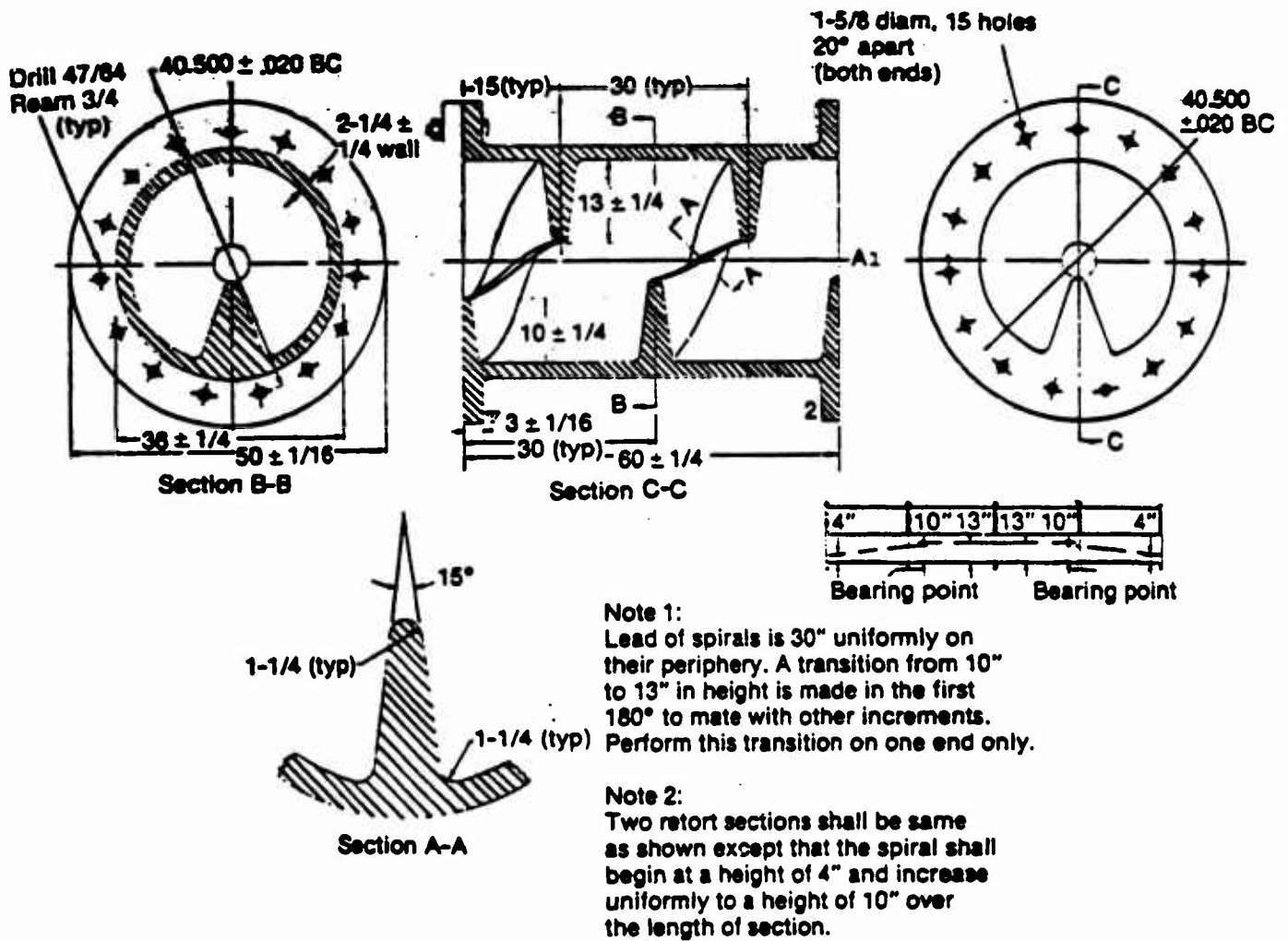
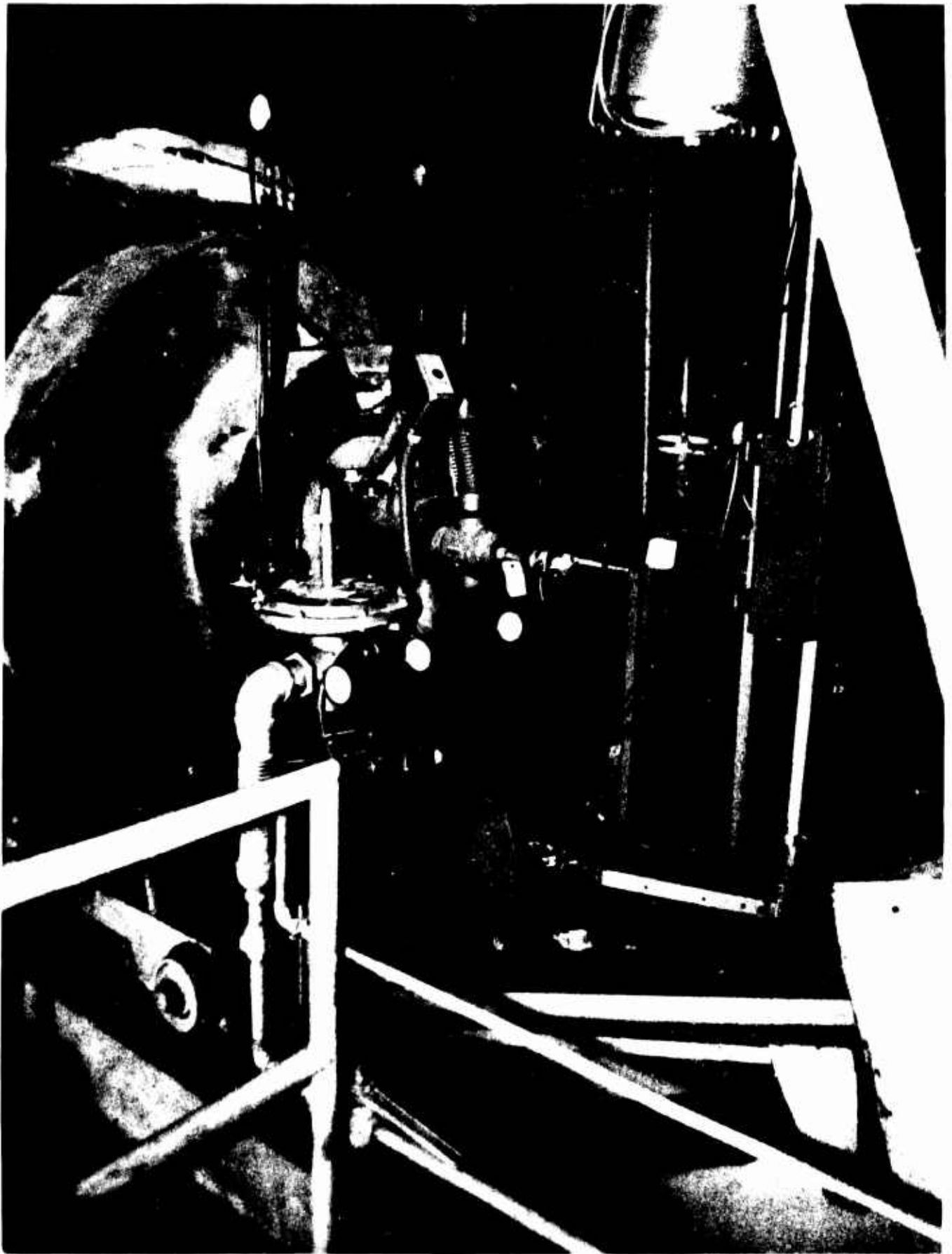FIGURE 3. RETORT SECTION FOR APE 1236 FURNACE

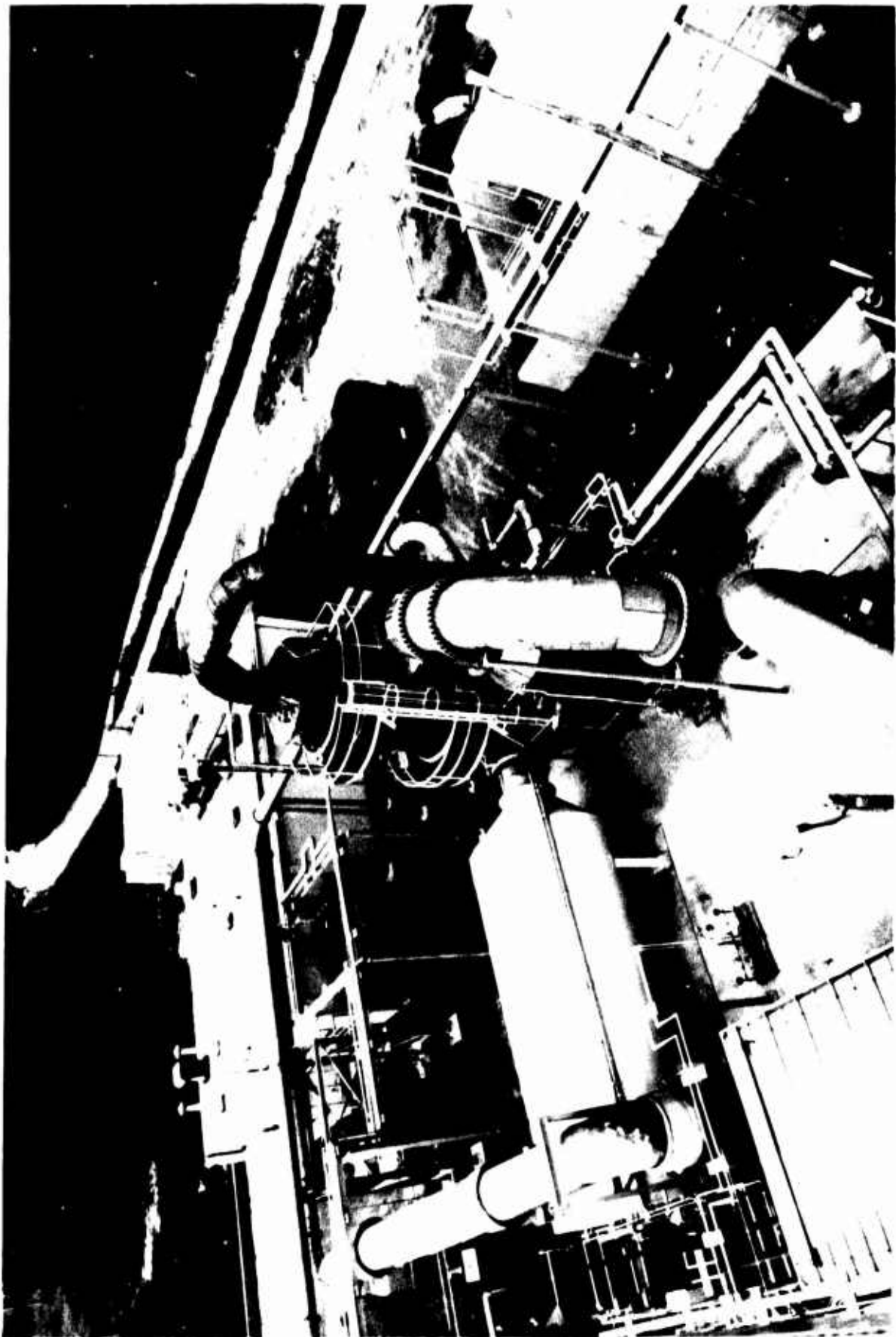FIGURE 4. DISCHARGE CONVEYOR AND BURNER OF APE 1236

FIGURE 5. POLLUTION CONTROL SYSTEM

The horizontally oriented fume afterburner was designed by Peabody Engineering. Its internal diameter is 9 feet 5 1/4 inches and its overall length is 32.5 feet. It is fired with natural gas and its temperature is controlled by a thermocouple monitoring the discharge temperature. The discharge temperature for these tests was set at 1800 F.

The quench was designed by Ducon Company, Inc. and is a size 96. The operating design data calls for a water supply of 27.5 gpm at 30 psig at each of two inlets.

A flue gas flow straightener was installed in the duct between the quench and venturi to prevent cyclonic flow and allow reliable duct sampling. For more details see Appendix II, Section 6.

The venturi scrubber is a Ducon Vertical Venturi Oriclone Cyclone, size 32/84, type VVD. The design is based on inlet conditions of 23,679 acfm at 166 F and 14.48 psia, 42.37 percent H_2O by volume and a molecular weight of 29 lb/lb-mole. The design outlet conditions are 26,312 acfm at 166 F saturated with water. The pressure drop at these conditions was designed to be 41.4 inches of water and the scrubbing water flowrate of the venturi is 211 gpm at 3-5 psig. The makeup water requirements are 15-20 gpm which is obtained from the potable water supply. The blowdown rate is constant at 15 gpm, and the blowdown water is directed to the industrial waste treatment plant.

4.4 INSTRUMENTATION

The SO_2 concentrations, used to estimate the burning time of the grenades, were determined by an International Biophysics Corp. Series NS 300 SO_2 analyzer which uses a Farester fuel cell detector. The oxygen concentrations in the flue gas leaving the deactivation furnace was monitored by a Taylor Servomex Type 0A272 O_2 analyzer, which uses a paramagnetic detector. The SO_2 and O_2 concentrations were recorded on a Honeywell Electronic 195 two-pen recorder. Figure 6 is a photograph showing part of the sampling system. The two analyzers and the recorder are located on the trunk in the center of the photograph. The gas sample for the analyzers was extracted from the flue gas duct through a sintered metal filter extending to the stack centerline*. The flue gas sample was passed through a series of glass impingers and then through approximately 30 feet of 1/4 inch O.D. x 1/8 inch I.D. polyethylene

* The sample port was located in a horizontal run of the duct between the furnace and the afterburner, where it passed over the deactivation furnace building.
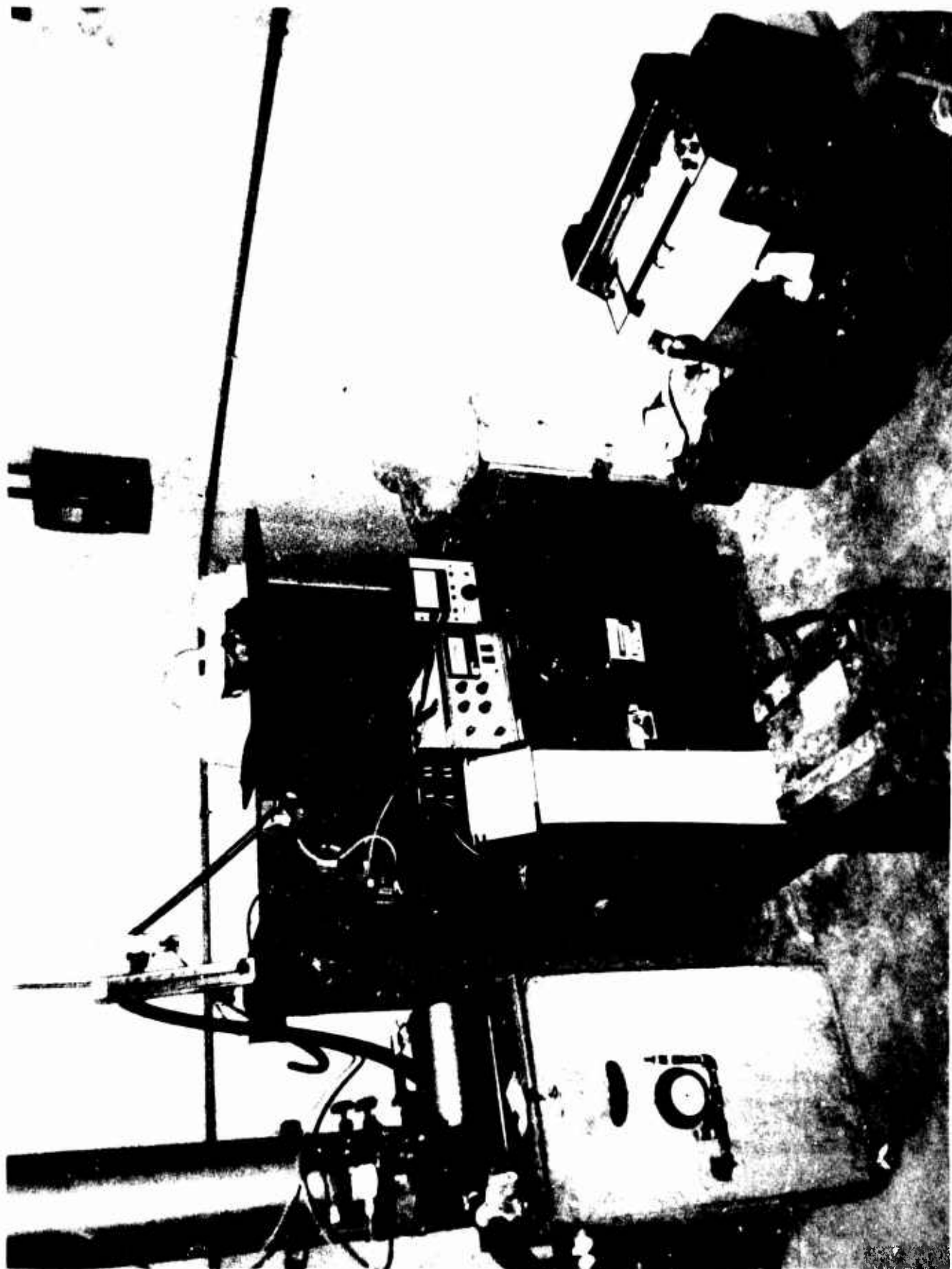
FIGURE 6. GAS SAMPLING ANALYSIS SYSTEM

tubing to a sampling pump. The discharge of the sampling pump was split, one stream being directed to a large flowmeter and the other stream to a small flowmeter. The stream from the small flowmeter was split, one branch being connected to the SO_2 analyzer and the other branch being connected to the O_2 analyzer. The flow to each analyzer was controlled by a small flo meter. The sampling system is illustrated in Figure 7. The total gas sampling rate was approximately 25 cfh and the flowrate to each analyzer was 1 cfh. The response time after SO_2 was introduced into the inlet of the sampling system was found to be 5 seconds. The response time to a change in the furnace firing rate, (which was indicated by a small peak in the O_2 concentration in the flue gas) was determined by noting the time difference between the closure of the natural gas control valve and the start of the O_2 peak, and was found to be 10 seconds.

The O_2 and SO_2 analyzers were periodically calibrated by using air (to zero the SO_2 analyzer and span the O_2 analyzer) and a span gas of 509 ppm SO_2 in nitrogen (to span the SO_2 analyzer and zero the O_2 analyzer).

The equipment used for stack sampling was provided by USAEHA and complied with requirements for EPA Methods 5, 7, and 8 sampling procedures.

A Raytek model R2LT computerized non-contract infrared thermometer was rented and used to obtain skin temperatures of the retort during operation.

Other instrumentation associated with the facility included a single pen, time shared temperature recorder for the burner and stack end thermocouples in the APE 1236 furnace, a single-pen recorder for the afterburner temperature, a position indicater for the afterburner make-up air, a position indicator for the variable throat of the ventrui scrubber, a pressure indicator for quench water, a position indicator for fume inlet valve to the afterburner and a flowmeter for fume flow to the afterburner. Instrumentation that was installed for these tests were a flowmeter for the natural gas flow to the deactivation furnace burner, an inlet orifice on the blower providing combustion air to the burner and a manometer to indicate pressure drop across the venturi.

5. PROCEDURE NARRATIVE

The five objectives, described in Section 2, were divided into two groups of tests. The tests for the first objective required feeding single M18 smoke grenades into the deactivation furnace and monitoring their behavior. The second through fifth objectives required feeding 8 M18 smoke grenades per minute, the equivalent feed rate for demilitarization of BZ munitions; these objectives were addressed simultaneously. The narratives of the two groups follows.
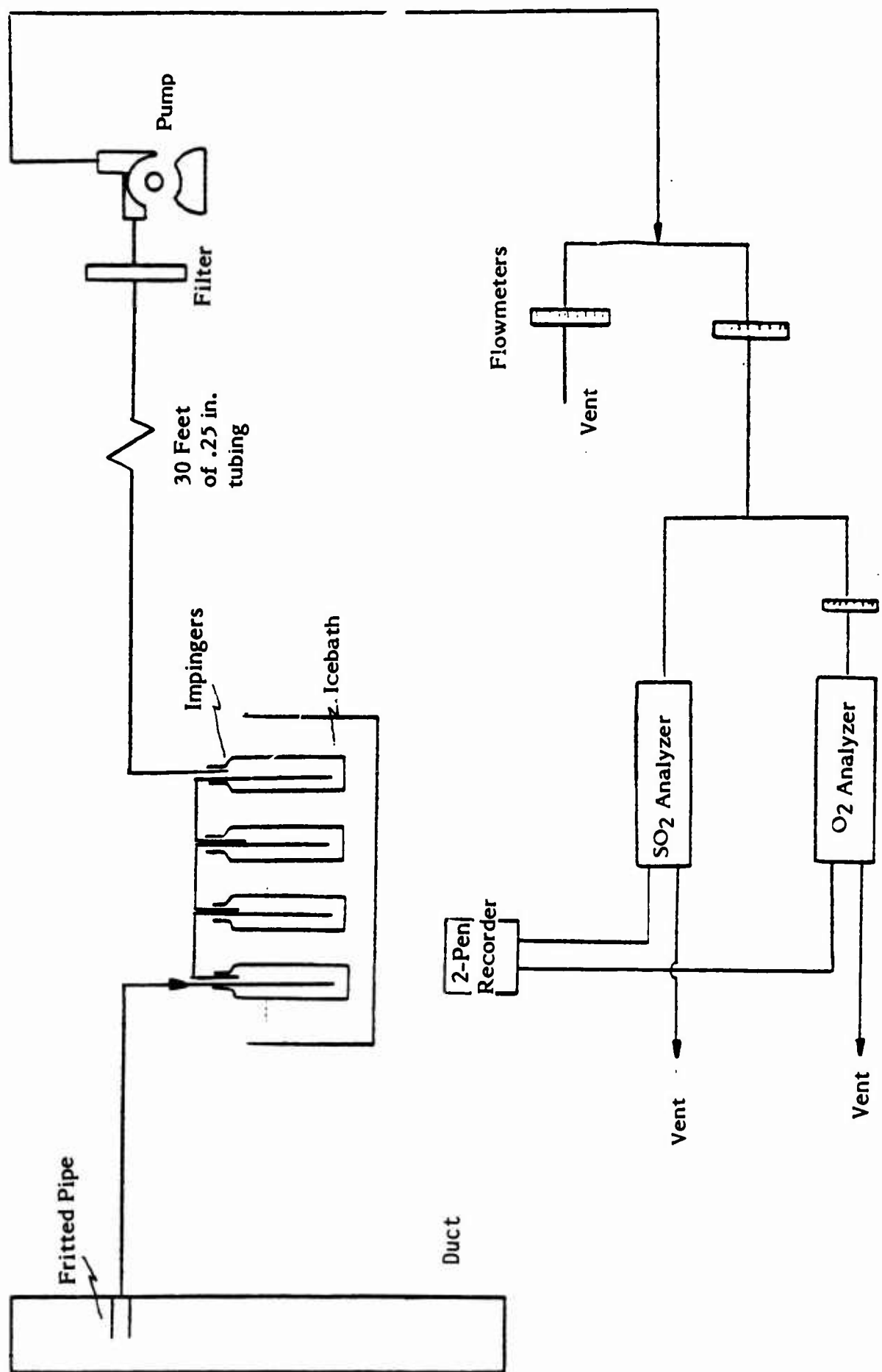
FIGURE 7. GAS SAMPLING SYSTEM

5.1 OBJECTIVE 1 NARRATIVE

Work at the incineration complex was initiated on November 30, 1981 by installing the O_2 and SO_2 gas sampling system in the flue gas duct of the APE 1236 furnace. The inlet orifice on the blower providing air to the deactivation furnace burner also was installed.

The incineration complex system was started up on the morning of December 1, 1981 and allowed to stabilize before the tests for Objective 1 were started. The deactivation furnace burner temperature was 1000 F and the exhaust temperature was 280 F for the start of the first test. The test conditions for the Objective 1 tests are tabulated in Table 2. Test A1 (the first test) was originally planned to be a test of the sampling system and the test procedures for Objective 1, the test went smoothly enough to allow the test results to be included in the Objective 1 test results. Two more tests, A2 and A3, were completed the same day.

To prepare for Objective 1 tests, the green M18 smoke grenades were unpacked and defuzed. The tapes covering the outlet holes were removed. The smoke grenades were soaked for two hours in water containing 0.01 percent Avirol III and then air dried (drained) in a vertical orientation for 22-24 hours. The weight of the grenades was recorded before and after soaking and after incineration.

Ten grenades were used for each of the Objective 1 tests. Before and after each test the operational conditions around the APE 1236 were recorded. The grenades were fed one at a time into the APE 1236 furnace. When the grenades entered the furnace (evidenced by the noise heard as they slid down the chute from the inlet conveyor) the time was marked on the recorder chart and a stop watch was started. The time between the initial appearance of the SO_2 spike and when the amplitude of the spike started to decrease was measured with a stopwatch and noted manually on the recorder chart. The stopwatch was stopped when the grenade was discharged from the furnace and the time recorded. With two stopwatches it was possible to feed the next grenade as soon as the initial grenades SO_2 spike reached a low amplitude. Figure 8 shows a section of the recorder chart during one of the tests. Observations made during the tests were recorded on the data sheets and in a laboratory notebook.

TABLE 2. OBJECTIVE 1 TEST CONDITIONS

Test ID	Time of One Retort Revolution, Sec	Burner Temperature, F
A-1	56	1000
A-2	42	1000
A-3	33	1000
A-4	32	800
A-5	14.5	800
A-6	13	1000
A-7	10	1200
A-8	15	1200
A-9	33	1200

19

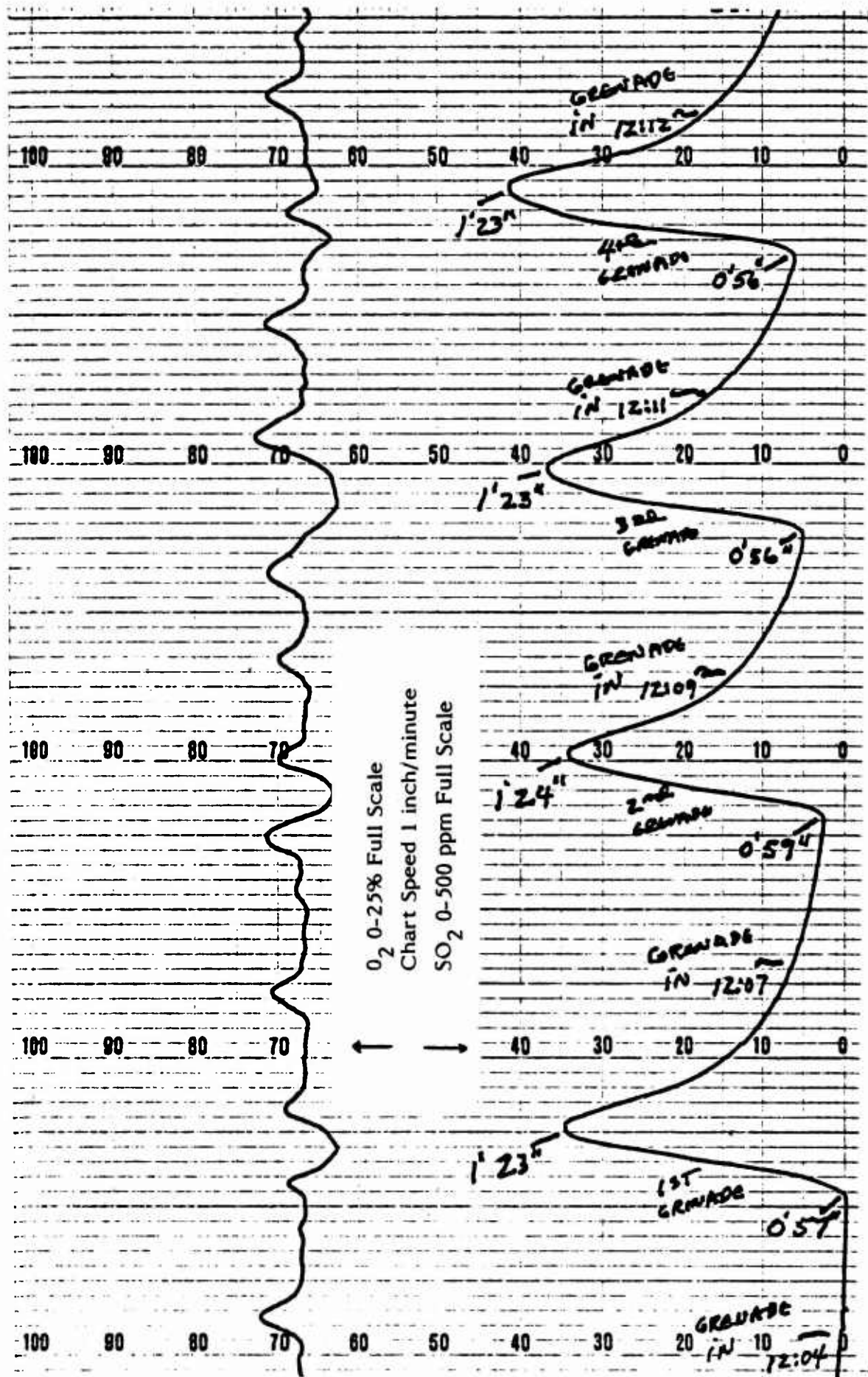FIGURE 8. SECTION OF TEST 7-A STRIP CHART

O_2 0-25% Full Scale
Chart Speed 1 inch/minute
SO_2 0-500 ppm Full Scale

Tests A4 and A5 were made on December 2, 1981 at a burner temperature of 800 F. The last four tests, A6, A7, A8 and A9 were completed on December 3, 1981 at a burner temperature of 1000 F for A6 and 1200 F for A7, A8 and A9.

5.2 OBJECTIVES 2 - 5 NARRATIVE

The preliminary results of the tests for Objective 1 were reviewed to determine system conditions for test Objectives 2 through 5. These objectives are listed below and the discussion of Objective 1 preliminary results which influenced the system operating conditions for Objectives 2 through 5 follows.

- Determine the effect of a feed rate of eight grenades per minute on the control of the deactivation furnace temperature

- Determine the composition, mass, and size of particulates generated by the incineration of grenades in the deactivation furnace

- Determine the effectiveness of the venturi scrubber in controlling particulate emissions from grenade incineration

- Determine the composition of the gaseous emissions from the afterburner.

The time to ignition of the M18 smoke grenades varied from 50 seconds at a burner temperature of 1200 F to approximately 3 minutes at a burner temperature of 1000 F (this was at a slow retort speed). Based on an average time to ignition of 1.5 minutes, a retort speed of approximately 2 rpm was chosen to position the grenade near the center of the furnace when it ignited. At this retort speed the average retention time of the grenade in the deactivation furnace was approximately 5 minutes.

Three tests made at the 2 rpm retort speed, at temperatures of 800 F, 1000 F, and 1200 F. No smoking of any of the grenades on exiting the deactivation furnace or signs of melted char were observed, therefore, the operating temperature of the deactivation furnace for Objectives 2 through 5 was chosen based on the amount of weight loss from the grenade; the greater the weight loss, the more the dye contained in the smoke grenade was volatilized. The weight loss is the difference between weight before inerting and after incineration.

Burner Temperature, F	Weight Loss, Grams (Average)
800	206.8
1000	210.3
1200	193.0

Because there did not appear to be a significant difference between the weight losses at the three temperatures, an operating temperature of 800 F was selected to minimize fuel consumption and reduce the potential for corrosion.

USAEHA personnel arrived Thursday morning, December 3, 1981 and set up their sampling systems. A pretest for Objectives 2 through 5 was conducted Friday, December 4, using M18 smoke grenades, unsoaked. The pretest allowed USAEHA to determine moisture, probe sizes, stack velocities and effectiveness of the flow straightener, and allowed Battelle to determine system conditions to prevent the discharge of smoke from the deactivation furnace at a feed rate of eight smoke grenades per minute.

A representative of Catalytic, Inc., arrived Sunday, December 6 and participated in the three tests performed the week of December 7th for Objectives 2 through 5. The first test was run Monday, December 7, 1981, at the following system conditions:

Afterburner temperature: 1800 F

Scrubber Pressure Drop: 20 inches water

Deactivation furnace flue flow: 1100 acfm (meter reading, uncorrected).

The filters from the EPA Method 5 sample trains, ahead of the venturi and at the stack, were relatively clean from the first test. It was decided from this observation that the next two tests would be run with a lower pressure drop across the scrubber. The lowest pressure drop that could be obtained with a minimum of system changes was 14 inches of water. The second and third tests were run on Tuesday and Wednesday.

The operating conditions used in the tests for Task 4 were effective in destroying M18 smoke grenades but will be modified to fullfill the requirements of the BZ demilitarization facility. The deactivation furnace proposed for the facility is 30 feet long furnace which will provide longer retention time of the munitions in the furnace. The deactivation furnace operating temperature of 800 F for the

Objectives 2 to 5 tests was selected based on data obtained from the destruction of M18 smoke grenades.

Violet, green, red and yellow M18 smoke grenades were used for Objectives 2 through 5 test activities. To overcome possible differences between test results attributable to a change in smoke color compositions during testing, the grenades were inventoried by color and a feed sequence was devised to keep the grenade feed mixture consistent throughout the tests. The feed sequence was

1 Yellow, 1 Red, 2 Green

1 Red, 1 Violet, 2 Green

1 Red, 1 Violet, 2 Green

2 Violet, 2 Green

1 Red, 2 Violet, 1 Green

Repeat.

None of the grenades burned for test Objectives 2 through 5 were soaked.

6. EXPERIMENTAL RESULTS

6.1 GENERAL OBSERVATIONS

6.1.1 Objective 1

None of the grenades incinerated during Objective 1 tests presented evidence of violent behavior such as bulged canisters, split seams, or audiable noise above the background noise of the furnace coinciding with ignition or functioning of the smoke grenades. Some of the grenades did, however, have slightly bulged ends which could be the result of expansion of the fill upon incineration.

In those tests in which the residence time of the grenades in the deactivation furnace were short, it was observed from the discharge opening in the furnace that pea sized bits of pyromix were sprayed from the grenade. Also, an occasional grenade could be heard functioning near the discharge opening of the furnace, sounding with a whoosh for a period of about 5 seconds.

As the incinerated grenades dropped from the furnace onto the discharge conveyor, small yellow flames were typically observed at the vent holes and fuze opening. The occurrence of the flames was more frequent at the shorter furnace residence times and were not observed during tests having long furnace residence times.

During later tests for Objective 1 the core temperature of the grenades was measured by the insertion of a Type K thermocouple into the center of the incinerated grenades. The temperature recorded as the core temperature was the maximum temperature observed on the digital readout. The time to reach the maximum temperature was approximately 1 minute. To reduce this time, the thermocouple was retained in the previous grenade until the next grenade exited the furnace. The core temperatures appear to be independent of the furnace operating temperature and appear to be the functioning temperature of the smoke grenades. The lower temperatures were measured in grenades having longer residence times, indicating that the grenades cooled down after functioning even at higher furnace operating temperatures. The average core temperatures and other averaged data gathered during Objective 1 tests are compiled in Table 3.

None of the smoke grenades incinerated in the Objective 1 tests showed external signs of the molten char, a glassy black coating. Three grenades from the Objective 1 tests, one from each temperature group (800, 1000, 1200 F), were sawed in half to check for internal signs of melting. All three of the canisters contained a dull black solid porous char, as shown in Figure 9. Molten char would be evident in the munition canister from areas of char that were dense and glassy. No signs of molten char were found.

6.1.2 Objective 2

Objective 2 was to determine the effect of a feed rate of eight grenades per minute on the control of the deactivation furnace temperature. To determine this effect, the burner temperature, exhaust gas temperature, and the retort skin temperatures at four locations were recorded every ten minutes. It should be noted that the 3rd and 4th retort sections (see Figure 10) were insulated with approximately 4 inches of insulation. The retort skin temperatures were taken 2 to 3 inches from the right side of the union between retort sections as illustrated in Figure 10 with a non-contact

TABLE 3. OBJECTIVE 1 TEST DATA

Test ID	Burner Temperature (F)	Average Time to Ignition (min)	Average Burn Time (min)	Average Residence Time (min)	Average Weight Loss (grams)	Position at Ignition (retort section)	Core Temperature (F)
A1	1000	2.24	0.68	8.58	205.1	2	-
A2	1000	2.08	0.71	6.68	207.0	2	-
A3	1000	1.68	0.60	5.47	210.3	2	-
A4	800	1.91	0.61	5.17	206.8	2	956
A5	800	1.43	0.55	2.12	208.9	3	1086
A6	1000	1.19	0.44	1.91	194.1	3	1152
A7	1200	0.862	0.43	1.43	173.6	3	1120
A8	1200	0.777	0.50	2.26	200.8	2	1153
A9	1200	0.817	0.47	5.14	193.1	1	1094
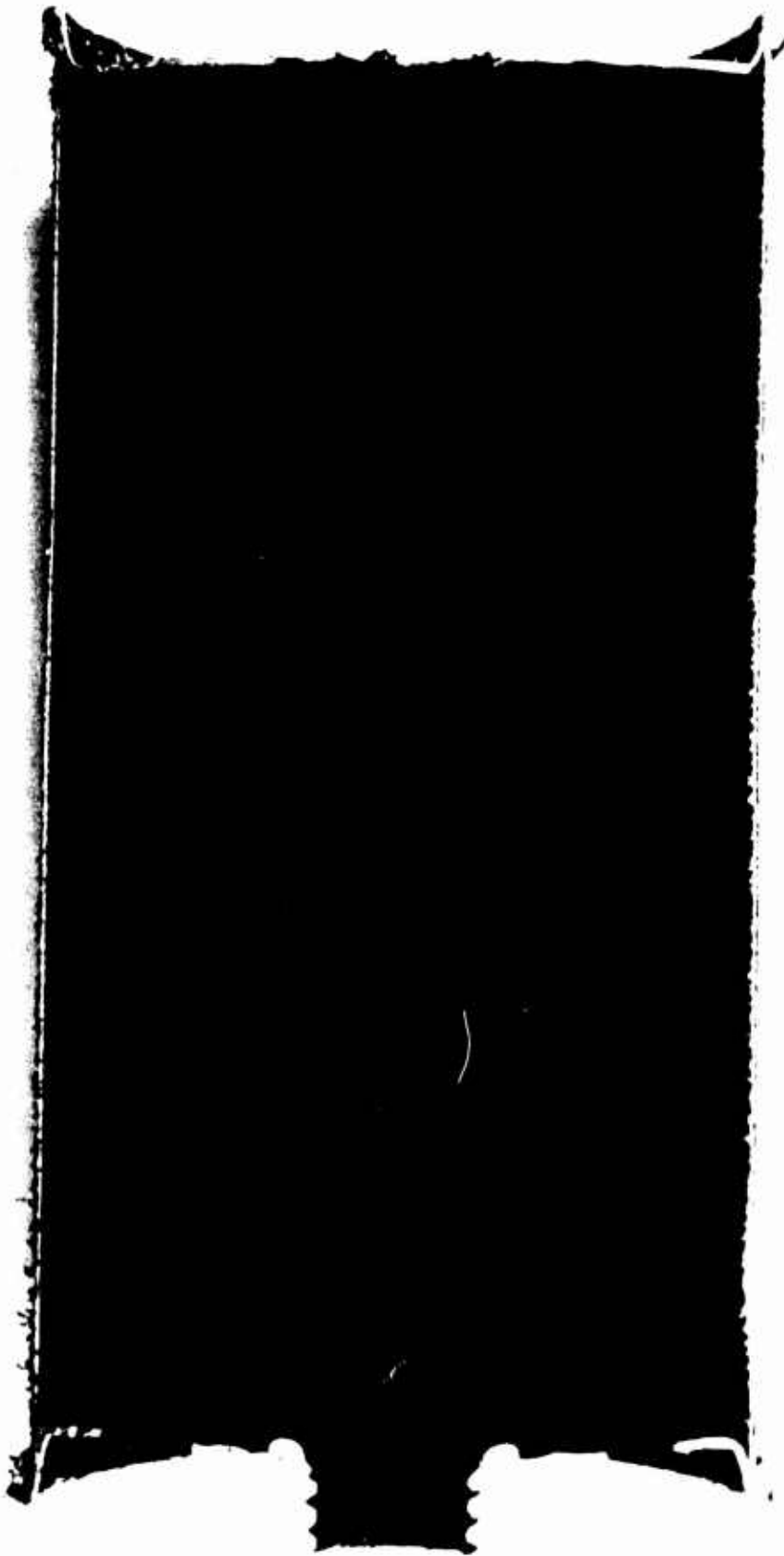
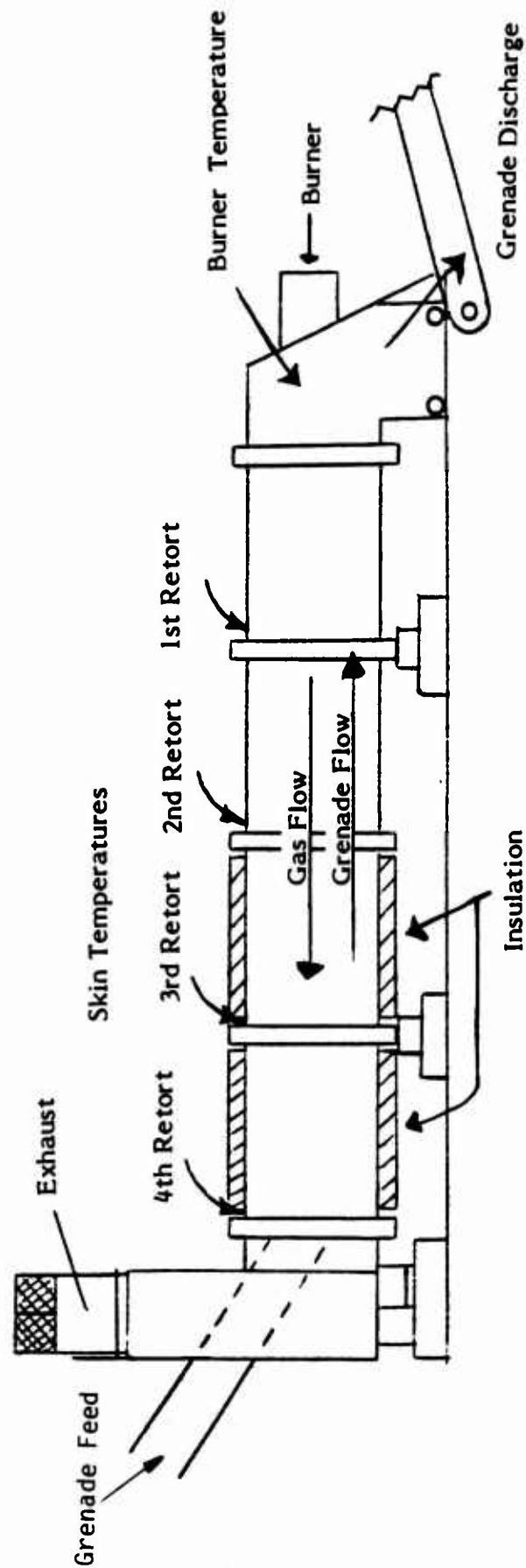FIGURE 9. M18 SMOKE GRENADE CHAR FROM OBJECTIVE 1 TEST A8

FIGURE 10. TEMPERATURE LOCATIONS RECORDED FOR OBJECTIVE 2 TESTS

pyrometer. The burner temperature was measured with a thermocouple located approximately 2 inches from the outside surface of the burner head. (The temperature of the burner was also taken with the pyrometer and the two temperature readings compared well.) The exhaust gas temperature was measured with a thermocouple located in the duct to the afterburner; this temperature was influenced by the dilution air entering the inlet chute and retort seal. Figure 11 is a plot of these temperatures versus time for the second test conducted on December 8, 1981. The graphs for the other two tests are included in Appendix II. From Figure 11 one can see that the 4th retort section and the exhaust temperature were dramatically effected by the starting and stopping of grenade feed. Both temperatures rose when the feed started and continued to rise until the feed was terminated.

The maximum duration of continuously feeding smoke grenades was 85 minutes. The skin temperature of the 4th retort section (the gas exhaust end of APE 1236) during this period increased steadily. Given the existing configuration, the final temperature that the 4th retort section might achieve during longer operation can be estimated to be the functioning temperature of the smoke grenade which is approximately 1200 F.

From the appearance of the SO_2 spike during the tests for Objectives 2 through 5 the unsoaked smoke grenades used for these tests were igniting approximately 50 seconds after entering the deactivation furnace. This would place the grenade near the junction of the 3rd and 4th retort sections (based on the retort speed of 1.8 rpm). This explains the little or no temperature rise in the 1st, 2nd, and 3rd retort sections.

The overall heat and mass balances around the deactivation furnace are illustrated in Figure 12. The overall balances agree well.

6.1.3 Objective 3

Test Objective 3 was accomplished by taking particulate samples upstream of the venturi and at the stack (see sample points numbers 2 and 5 from Figure 13). The particulate mass loading was determined by using an EPA Method 5 sampling system illustrated in Figure 14 and the results are presented in Table 4. Also tabulated in Table 4 are the particulate loadings corrected to 12 percent carbon dioxide, without the contribution of auxiliary fuel (as required by state regulations to correct for dilution effects). The particulate mass loadings are well below the Arkansas air pollution regulation of 0.2 grains of particulate matter per standard cubic foot of dry flue gas corrected to 12 percent carbon dioxide, without the contribution of auxiliary fuel.
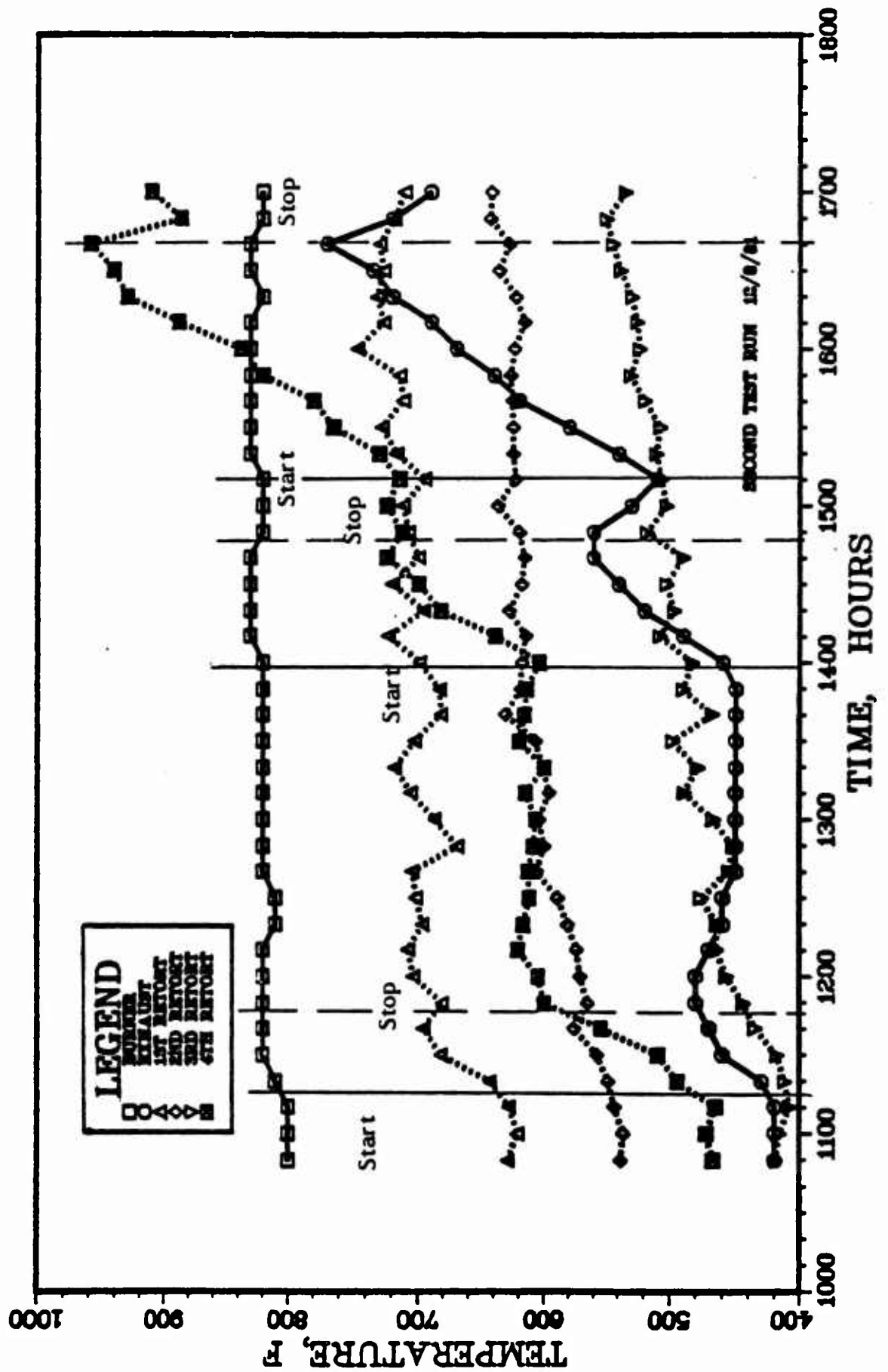
FIGURE 11. TEMPERATURE VS TIME GRAPH OF DEACTIVATION FURNACE
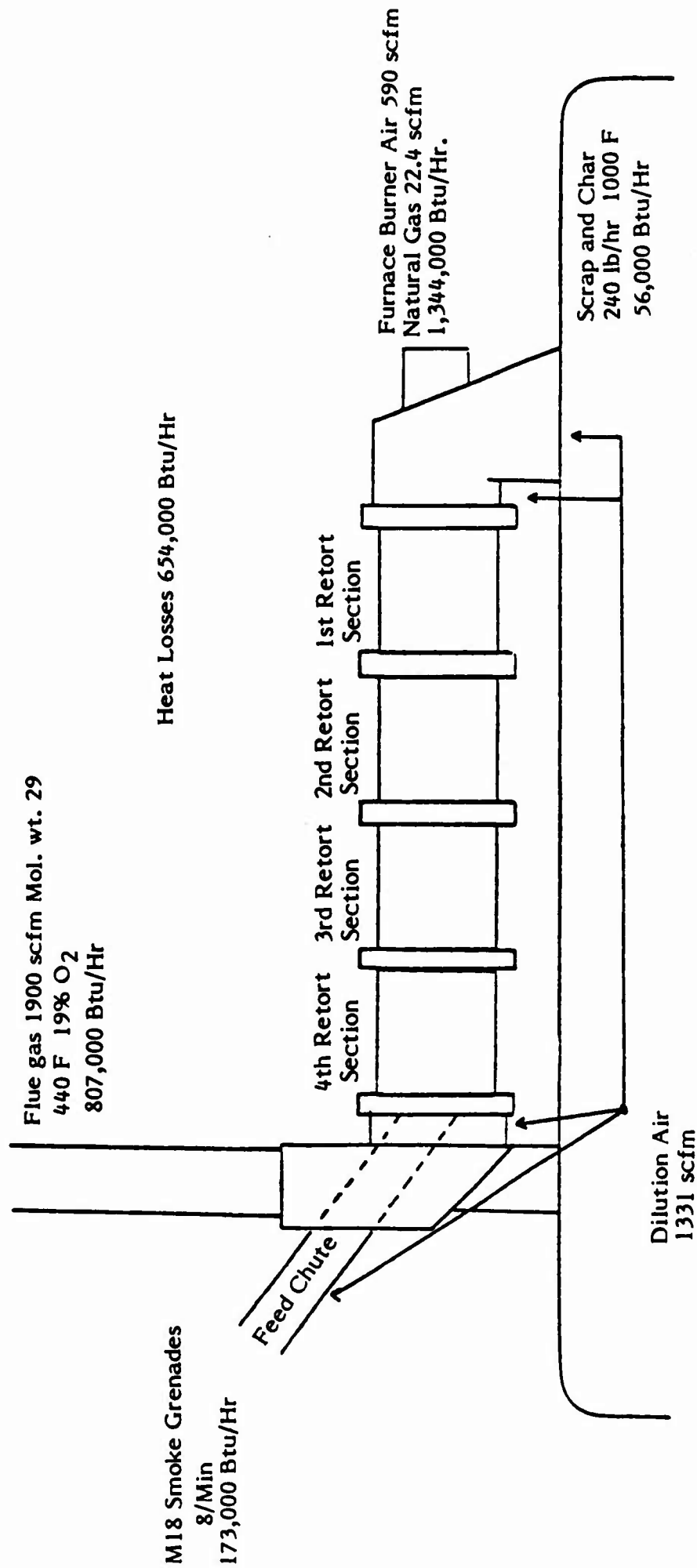
FIGURE 12. HEAT AND MASS BALANCE AROUND APE 1236

Furnace Burner Air 590 scfm
Natural Gas 22.4 scfm
1,344,000 Btu/Hr.

Scrap and Char
240 lb/hr 1000 F
56,000 Btu/Hr

Heat Losses 654,000 Btu/Hr

1st Retort Section

2nd Retort Section

3rd Retort Section

4th Retort Section

Flue gas 1900 scfm Mol. wt. 29
440 F 19% O$_2$
807,000 Btu/Hr

Dilution Air
1331 scfm

Feed Chute

M18 Smoke Grenades
8/Min
173,000 Btu/Hr

30
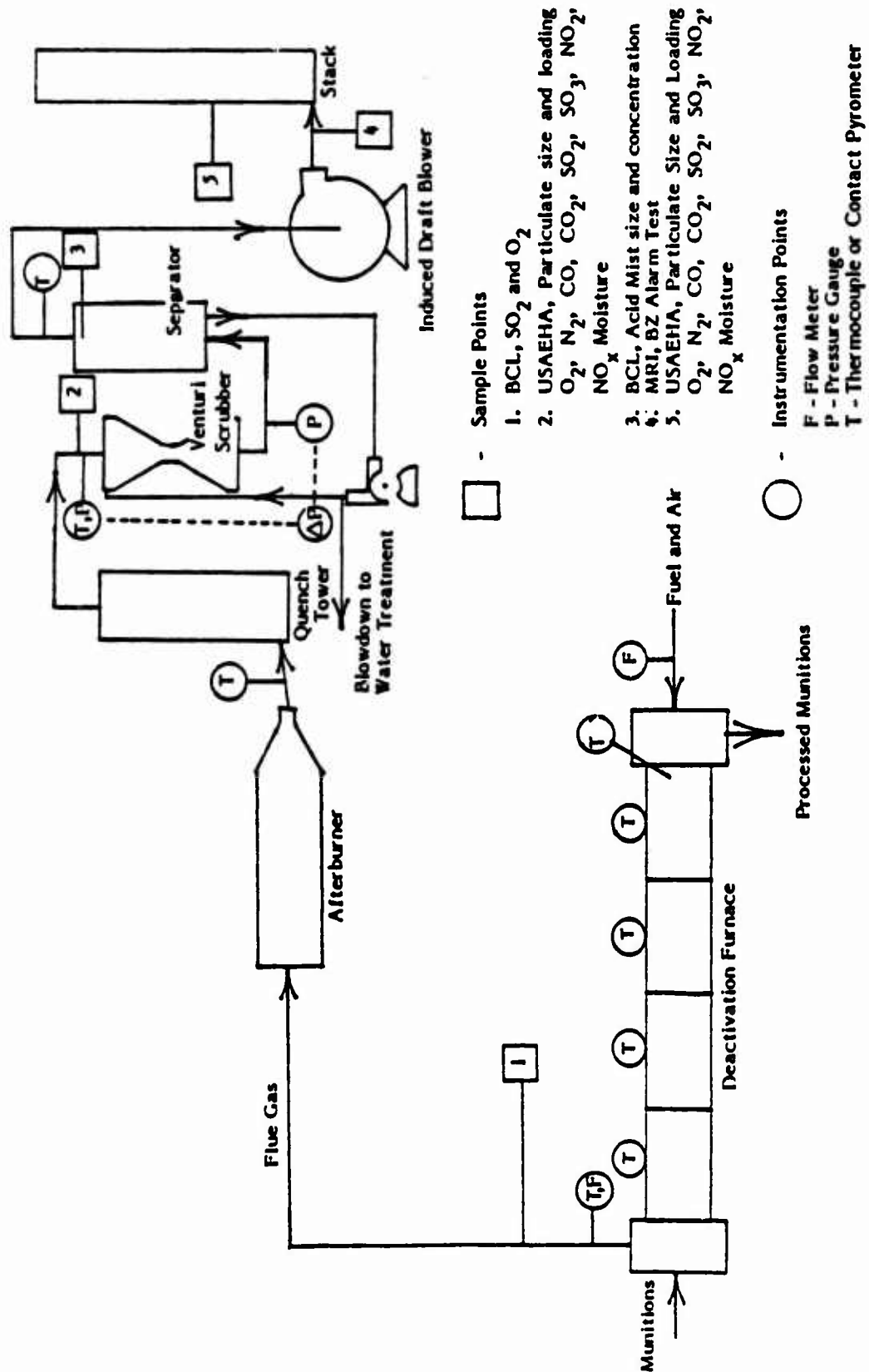
FIGURE 13. SYSTEM SCHEMATIC

Sample Points

1. BCL, SO_2 and O_2
2. USAEHA, Particulate size and loading
   O_2, N_2, CO, CO_2, SO_2, SO_3, NO_2, NO_x Moisture
3. BCL, Acid Mist size and concentration
4. MRI, BZ Alarm Test
5. USAEHA, Particulate Size and Loading
   O_2, N_2, CO, CO_2, SO_2, SO_3, NO_2, NO_x Moisture

Instrumentation Points

F - Flow Meter
P - Pressure Gauge
T - Thermocouple or Contact Pyrometer

Stack

Induced Draft Blower

Separator

Venturi Scrubber

Quench Tower

Blowdown to Water Treatment

Afterburner

Flue Gas

Fuel and Air

Processed Munitions

Deactivation Furnace

Munitions

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FIGURE 14. PARTICULATE SAMPLING SYSTEM EPA METHOD 5

TABLE 4. PARTICULATE MASS LOADING DATA[a]

Run Number	Scrubber ΔP (in. H_2O)	Location	C's (gr/dscf)	C's (lb/hr)	C's Corrected to 12% CO_2 (gr/dscf)
1	20	Quench	.00016	.00470	.011
		Stack	.000020	.00204	.00040
2	14	Quench	.00013	.00617	.011
		Stack	.000039	.00283	.0047
3	14	Quench	.000078	.00451	.0016
		Stack	.000044	.00345	.0013

(a) Operating Conditions: Deactivation Furnace, 800 F; Afterburner, 1800 F

The size distribution of the particulate matter was determined by using an Anderson Mark III Impactor at the same sample locations as were used for particulate loading determinations. The results of the size distribution determinations are presented in Table 5. The particle diameter listed is the diameter at which the stage collection efficiency is 50 percent at the testing conditions. The particulate loading measurements were made at the start and completion of each test signified by the A and B respectively.

The majority of the particulate entering the venturi scrubber is sub-micron in size. The effectiveness of a venturi scrubber at low pressure drops for removing sub-micron particles is poor as the data indicates. The percentage of sub-micron particulate at the stack is higher, indicating that the venturi scrubber did remove the larger particulate.

6.1.4 Objective 4

The effectiveness of the venturi scrubber in controlling particulate emissions from the destruction of pyrotechnic munitions was determined by comparing the differences of the particulate loading measured upstream and downstream of the venturi scrubber. The calculated efficiencies of the venturi for particulate removal were 57, 54 and 24 percent removal at pressure drops across the venturi of 20, 14 and 14 inches of water respectively. The second test result of 54 percent is questionable due to sampling problems encountered during the test.

Mist generated during normal operation of a venturi scrubber in the presence of a gas that forms an acid with water, forms an acid mist. Most of the acid mist is removed in a mist-eliminator; however, small droplets of acid are carried through the mist eliminator and can result in a corrosion problem in the following pollution control system and a problem of opacity at the stack. To be able to design a pollution control system to control emissions of acid mist, it is helpful to know the amount and the size distribution.

The procedure used for determining an estimate of the droplet size distribution consisted of taking a sample of flue gas at the outlet of the separator. This is sample point 3 on Figure 13. The sample stream was pulled through an assembly of three Buchner-type fritted glass filter funnels in series, illustrated in Figure 15. The funnels were oriented such that the flue gas sample was passed through sequentially smaller pore-sized fritted glass filters. The first fritted filter had nominal pore-size openings of 40 to 60 micrometers; the second, 10 to 15; and the

TABLE 5. PARTICULATE SIZE DISTRIBUTION DATA

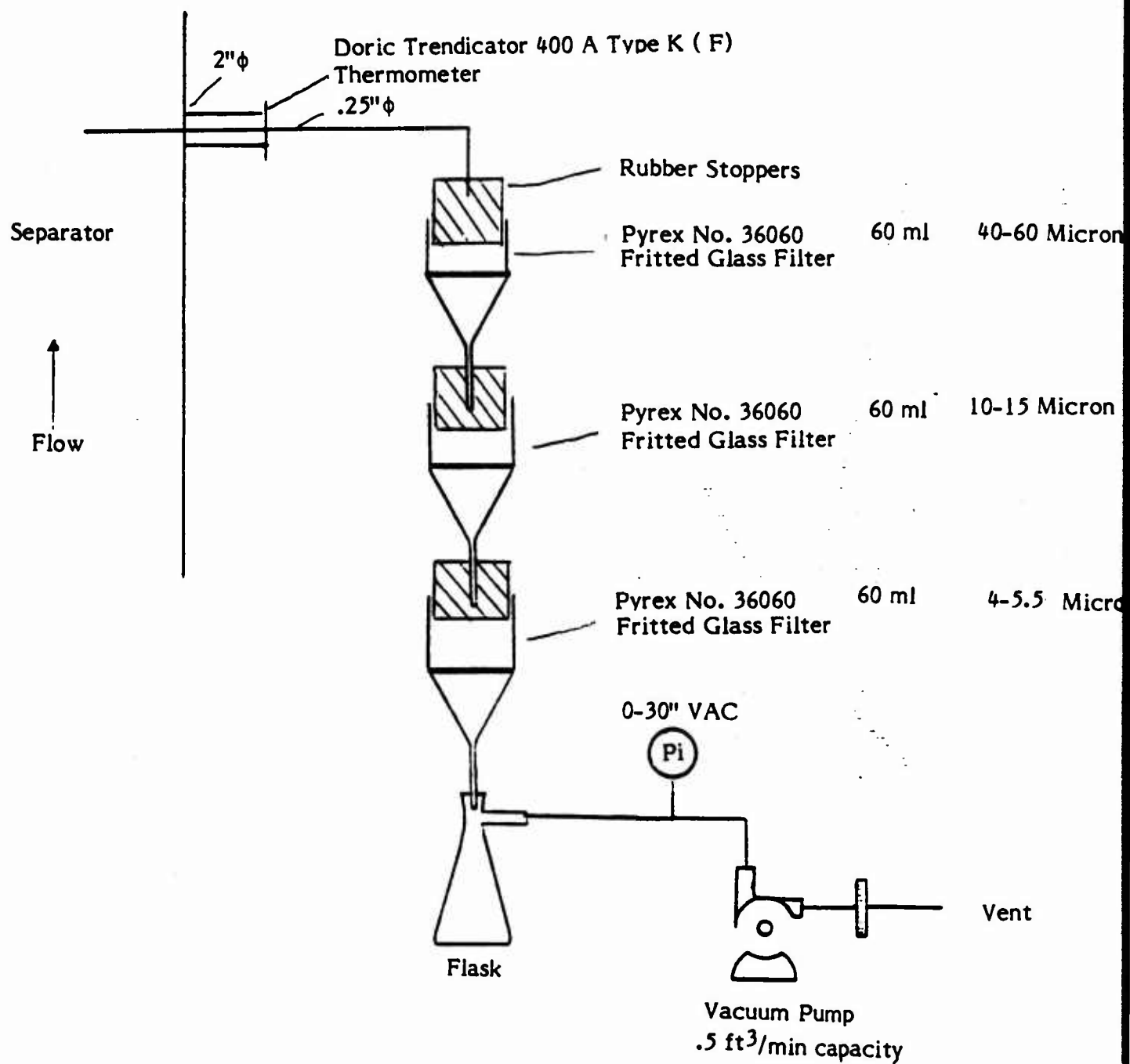| Run	Sample Position	Stage No.	1	2	3	4	5	6	7	8	Filter	Totals
1-A	Quench	Particle Diam. μm	12.4	7.7	5.0	3.5	2.2	1.1	0.7	0.4	–	
		wt. collected	0.00	0.00	0.10	0.00	0.00	0.00	1.23	5.53	25.40	32.26
		% of total collected	0.0	0.0	0.3	0.0	0.0	0.0	3.8	17.1	78.8	100.0
1-A	Stack	Particle Diam. μm	13.4	8.0	5.7	3.8	2.4	1.3	0.78	0.51	–	
		wt. collected	0.00	0.00	0.00	0.00	0.00	0.13	0.00	0.00	27.86	27.99
		% of total collected	0.0	0.0	0.0	0.0	0.0	0.5	0.0	0.0	99.5	100.0
1-B	Quench	Particle Diam. μm	15.3	9.4	6.5	4.4	3.0	1.4	0.9	0.6	–	
		wt. collected	45.86	0.00	0.00	0.00	0.00	0.23	1.26	0.96	15.58	63.89
		% of total collected	71.8	0.0	0.0	0.0	0.0	0.4	2.0	1.5	24.4	100.0
1-B	Stack	Particle Diam. μm	13.5	8.2	6.1	3.9	2.4	1.3	0.8	0.52	–	
		wt. collected	0.31	0.29	0.15	0.85	0.27	0.83	1.24	2.81	29.72	36.47
		% of total collected	0.9	0.8	0.4	2.3	0.7	2.3	3.4	7.7	81.5	100.0
2-A	Quench	Particle Diam. μm	13.9	8.7	5.8	3.9	2.5	1.2	0.9	0.5	–	
		wt. collected	0.08	0.00	0.00	0.00	0.00	0.61	7.81	9.04	29.28	46.82
		% of total collected	0.2	0.0	0.0	0.0	0.0	1.3	16.7	19.3	62.5	100.0
2-A	Stack	Particle Diam. μm	15.9	10.2	6.8	4.5	2.9	1.4	0.9	0.6	–	
		wt. collected	0.53	2.69	0.00	0.00	0.00	0.00	0.00	7.06	29.36	39.64
		% of total collected	1.3	6.8	0.0	0.0	0.0	0.0	0.0	17.8	74.1	100.0
3-A	Quench	Particle Diam. μm	13.7	8.4	5.7	3.9	2.4	1.2	0.8	0.5	–	
		wt. collected	3.64	0.00	0.00	0.00	0.00	0.00	0.00	5.88	11.97	21.49
		% of total collected	16.9	0.0	0.0	0.0	0.0	0.0	0.0	27.4	55.7	100.0
3-A	Stack	Particle Diam μm	16.3	10.3	6.9	4.8	3.0	1.5	0.9	0.6	–	
		wt. collected	0.00	3.32	1.97	0.00	0.00	0.00	11.20	0.00	38.28	54.77
		% of total collected	0.0	5.6	3.3	0.0	0.0	0.0	18.8	0.0	64.2	100.0
3-B	Quench	Particle Diam μm	12.9	7.9	5.3	3.7	2.3	1.2	0.7	0.5	–	
		wt. collected	17.67	1.20	0.00	0.00	0.00	7.58	1.27	7.53	24.40	59.65
		% of total collected	29.6	2.0	0.0	0.0	0.0	12.7	2.1	12.6	40.9	100.0
3-B	Stack	Particle Diam μm	15.1	9.4	6.4	4.4	2.7	1.4	0.9	0.6	–	
		wt. collected	15.04	2.04	1.10	1.33	3.88	1.15	6.91	7.32	35.29	74.06
		% of total collected	20.3	2.8	1.5	1.8	5.2	1.6	9.3	9.9	47.7	100.0

FIGURE 15. ACID MIST SIZE DETERMINATION APPARATUS

third, 4 to 5.5. The final catch, any acid mist which was not collected on the fritted glass filters, was collected in a vacuum filter flask. A constant flow of 0.5 cfm was pulled through the acid mist collection unit with a vacuum pump. The flow rate was monitored with a flowmeter mounted on the vacuum pump exhaust.

At the conclusion of a measured period of time, the collection unit was dissaembled. Each filter's funnel was washed with distilled water and the wash water collected and placed into a glass bottle. A separate bottle was used for each funnel washdown water. Thus, four discrete samples were recovered from each test. There were three of the acid mist determination tests made during each of the second and third runs for Objectives 2 through 5.

Prior to their analysis, each sample was gently boiled. The pretreatment of boiling the sample, removed any dissolved sulfur dioxide which could be an interferent in the analytical method. The standard barium-thorion titration method for sulfate concentration was used (Reference; Federal Register, Vol. 42, No. 160, pages 41786-41789). Due to the concentration of sulfate from the sulfuric acid being close to the detection limit of the analytical method, it was necessary to add a spike of standard sulfuric acid solution to each aliquot before titration. The addition of the spike made the titration end-point easy to read. The results are tabulated in Table 6. Also tabulated in Table 6 are the acid mist plus SO_3 measurements taken before and after the venturi scrubber by USAEHA using EPA Method 8. The measurements from USAEHA are more reliable for the total acid mist and SO_3 emissions due to the nature of the EPA Method 8 using bubblers; whereas, the size distribution method used has no final absolute trap to capture all the acid mist sampled.

From the data presented in Table 6, the total emission of sulfuric acid mist is well below the Arkansas State ambient standards for sulfur trioxide and sulfuric acid mist of 30 mg/m^3. By using USAEHA's dispersion model and a stack height of 45 m the ambient concentrations based on the stack concentrations were calculated and are also presented in Table 6. The calculated ambient concentrations are three orders of magnitude below the state standard. This was visually substantiated by observing the plume exiting the stack. The opacity was normally zero with small excursions of up to 5 percent. Normally the plume completely dissapated in less than 200 feet from the stack.

TABLE 6. SUMMARY OF SULFURIC ACID MIST DROPLET SIZE DISTRIBUTION

	Run 02, 12/8/81			Run 03 - 12/9/81		
	1116-1157	1403-1445	1520-1620	1205-1245	1415-1530	1700-1731
Droplet Size Catch						
40-60 µg/CF	98.5	105.0	89.8	158.8	101.9	214.9
percent of Total	(21)	(40)	(26)	(22)	(14)	(25)
10-15 µm, µg/CF	56.9	53.9	49.7	95.7	79.9	74.3
percent of Total	(12)	(20)	(15)	(13)	(11)	(9)
4-5.5 µm, µg/CF	75.9	28.0	70.9	99.9	73.2	142.3
percent of Total	(16)	(11)	(21)	(14)	(10)	(17)
<4.5-5 µm, µg/CF	246.6	77.0	130.7	367.5	476.3	429.9
percent of Total	(52)	(29)	(38)	(51)	(65)	(50)
Total, µg/CF	477.9	263.9	341.2	721.8	731.3	861.4
percent of Total	(100)	(100)	(100)	(100)	(100)	(100)
Average of 3 tests		361.7 µg/CF			771.5 µg/CF	

	Run 1		Run 2		Run 3	
	Quench	Stack	Quench	Stack	Quench	Stack
H_2SO_4 mist + SO_3 USAEHA Measurements mg/CF	10.3	3.94	*	3.42	5.96	1.64
Dispersion Modeled Ambient Concentration, µg/m³	10.6	11.8	*	7.20	10.1	3.80

* Data lost due to breakage of glassware within sampling equipment during test.

6.1.5 Objective 5

To complete the overall emissions determination, it was necessary to know the composition of the flue gas entering and leaving the pollution control system of the Incineration Complex during incineration of the pyrotechnic munitions. The flue gas flowrate and composition at the quench and stack for each of the three test runs are presented in Table 7.

The applicable state standard of gaseous emissions of concern is for SO_2 which is an ambient concentration of 0.2 ppm SO_2. The highest calculated ambient concentration of SO_2 from the test results was 0.03 ppm SO_2 after the quench. This is well below the state standard.

See Reference 5, USAEHA report, for more detail.

6.2 TIME TO IGNITION

The time to ignition of the inerted M18 smoke grenades in Objective 1 tests was estimated by determining the time between the entrance of the grenade into the furnace, which was audiable, and the first appearance of SO_2 at the analyzer, correcting for delays associated with

- Transport of gas from the burning grenade to the sample port in the deactivation furnace stack
- Transport of gas through the sampling line and response time of the SO_2 detector/analyzer.

The time of transport of gas from the burning grenade to the inlet of the sample line is a function of the gas flowrate through the deactivation furnace and the position of the grenade in the retort. This correction turns out to be only a maximum of 2 seconds if the grenade begins to function at the discharge end of furnace and at low operating temperatures in the furnace. Also the exact location of the grenade was unknown so this correction was neglected. The correction for the sampling system response time is 5 seconds.

The average times to ignition are presented in Table 3 for each of the nine tests done for Objective 1. Figure 16 illustrates that the time to ignition decreases with an increase in temperature. The two points that appear to disagree with this

TABLE 7. GASEOUS EMISSIONS

	Run 1		Run 2		Run 3	
	Quench	Stack	Quench	Stack	Quench	Stack
SO_2 (ppm)	582	152	*	180	241	182
NO_x (ppm)	56	22	45	45	20	50
HCl (mg/m^3)	121	7	60	3	75	5
Cl_2 (mg/m^3)	4.6	3.1	45.8	2.7	7.4	3.1
CO_2 (%, Vol.)	5.5	2.0	5.0	3.4	5.0	3.6
N_2 (%, Vol.)	82.1	80.0	81.6	81.0	82.1	80.9
O_2 (%, Vol.)	12.4	18.0	13.4	15.6	12.9	15.5
Flowrate (dscfh)	246,773	722,390	335,033	502,157	405,977	554,801

* Data lost due to breakage of glassware during test.
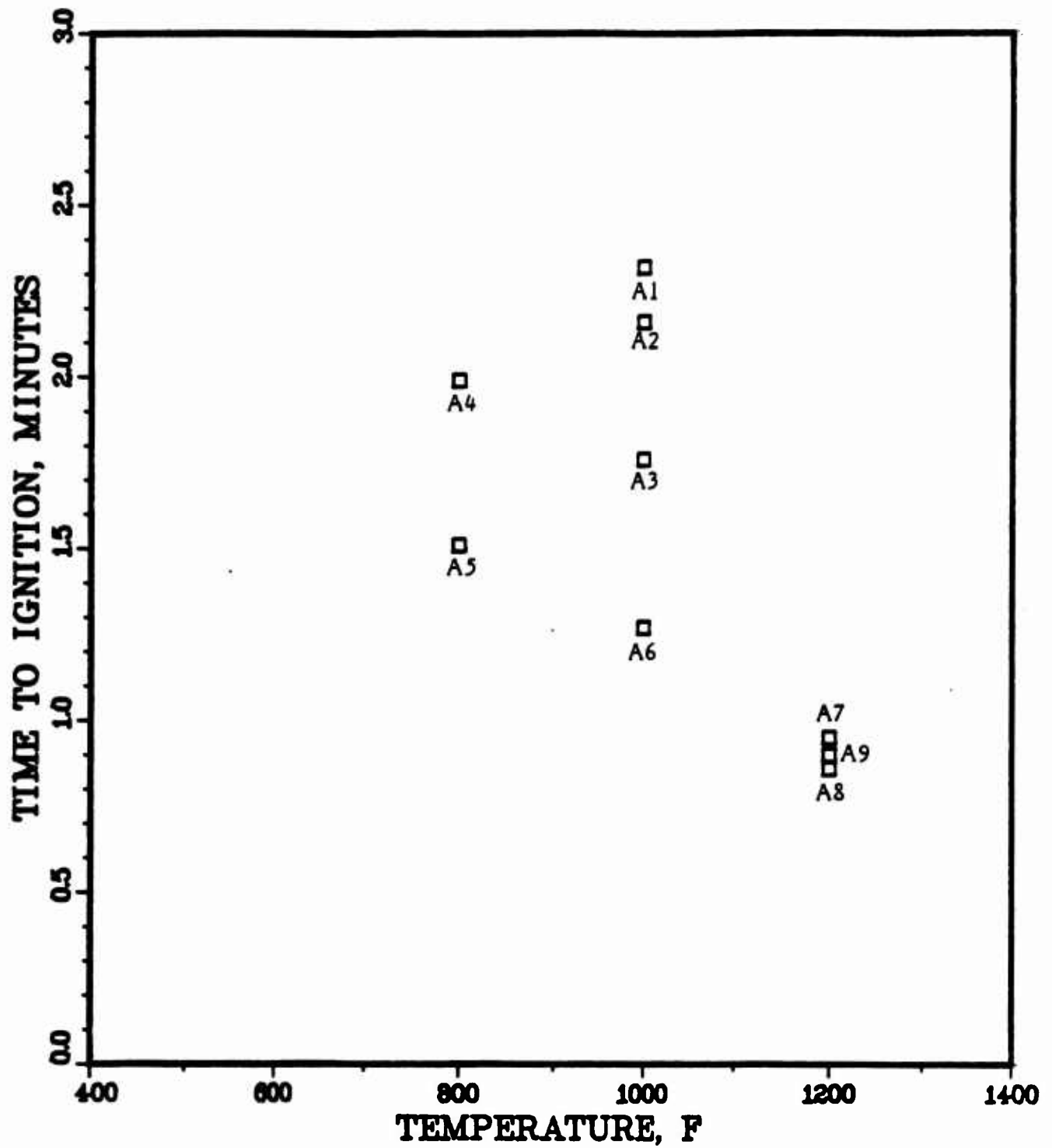
FIGURE 16. TIME TO IGNITION VS BURNER TEMPERATURE

effect are for two tests (A1, A2) in which the grenades were moved through the furnace much slower than other tests. The smoke grenades were not subjected to the burner temperature as soon as in other tests.

A regression analysis was performed on the experimental data to obtain a correlation of the time to ignition with burner temperature and time to discharge. The resulting regression equation is:

$$Y = 2.88 - 0.002 \, X1 + 0.147 \, X2$$

where Y = time to ignition (minutes)

$X1$ = burner temperature (F)

$X2$ = residence time (minutes).

6.3 BURN TIME

The method used to obtain a measure of the M18 smoke grenade burn time in the APE 1236 deactivation furnace was to measure SO_2 concentration in the exhaust gas and record the concentration as a function of time. The SO_2 concentration traces for the incinerated grenades increased from zero concentration to a peak in approximately 40 seconds followed by a rapid decline and a tail. The tail is the result of sulfurous gases still being emitted from the spent grenade while in the furnace. This gaseous emission was varified by the sulfurous odors omitted from the discharged grenades which had stopped "normal" burning. The char was still glowing red, driving off sulfur that was still contained in the char. The "normal" burning times have been assumed to be equal to the time from the first appearance of SO_2 (from combustion of sulfur in the grenade) to the peak value.

The burn times so determined from the SO_2 concentration traces are tabulated in Table 3 and are plotted with respect to burner temperature in Figure 17. There is a decrease in burn time with an increase in temperature. Also as with time to ignition, there is a strong dependence on the position of the smoke grenade in the deactivation furnace as to the actual temperature the smoke grenade is subjected. This is reflected by the points for tests A1, A2 and A6. Tests A1 and A2 were such that the smoke grenades were not subjected to the flame temperature during burning and A6 was such that the smoke grenades were directly under the flame while burning.
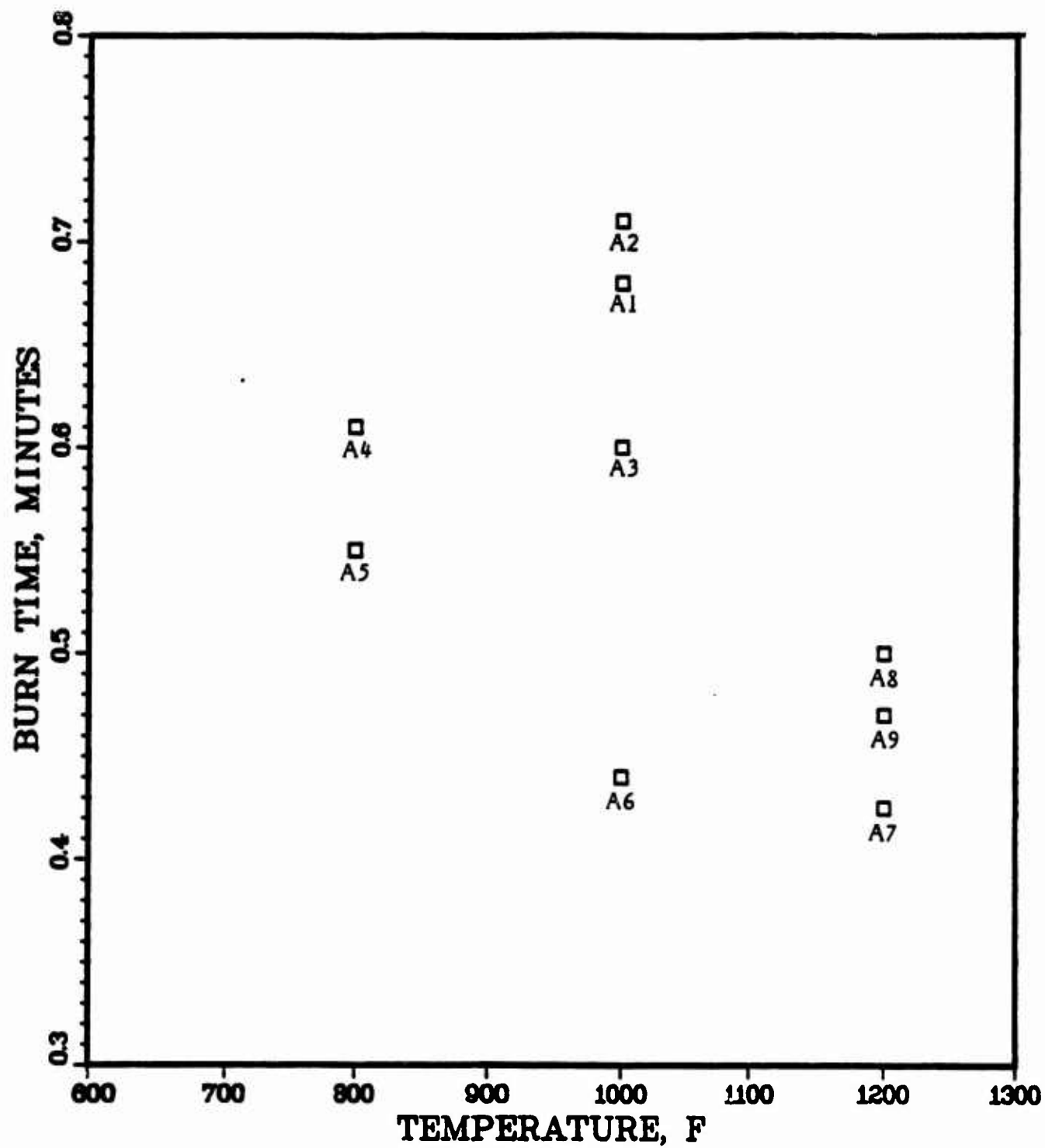
FIGURE 17. BURN TIME VS. BURNER TEMPERATURE

The regression equation obtained from the experimental data is:

$$Y = 0.646 - 0.0002\ X1 + 0.0319\ X2$$

where   Y   = burn time (minutes)

         X1   = burner temperature

         X2   = residence time (minutes).

6.4 WEIGHT LOSS

The weight loss of the M18 smoke grenades is the weight difference between the smoke grenades weight before and after incineration. The higher the weight loss the more complete the volitilization of the pyrotechnic mixture. This weight loss could also be an indication of molten char and/or rough handling resulting in char being discharged from the canister. There were no indications of molten char in any of the smoke grenades from Objective 1 tests and all the smoke grenades received the same amount of handling. There were indications of char being sprayed from the vent holes of the canisters and this was observed in tests in which the grenades were near the discharge opening of the deactivation furnace. In these tests as the grenade functioned, sparks of burning char could be observed spraying out of the discharge opening of the deactivation furnace. It would be expected that the shorter burn times would result in higher weight loss due to more energetic burning, Figure 18 indicates that the inverse is true. These arguments appear to rule out all but the weight loss being a result of the pyrotechnic mixture volitilization.

A regression of the experimental data gives the following correlation

Y   = 225. - 0.027 X1 + 1.24 X2

where   Y   = weight loss (grams)

         X1   = burner temperature (F)

         X2   = residence time (minutes).

The regression equation indicates that as the residences time increases, the weight loss will continue to increase; however, the data graphed in Figure 19 appears to indicate that a maximum is reached.
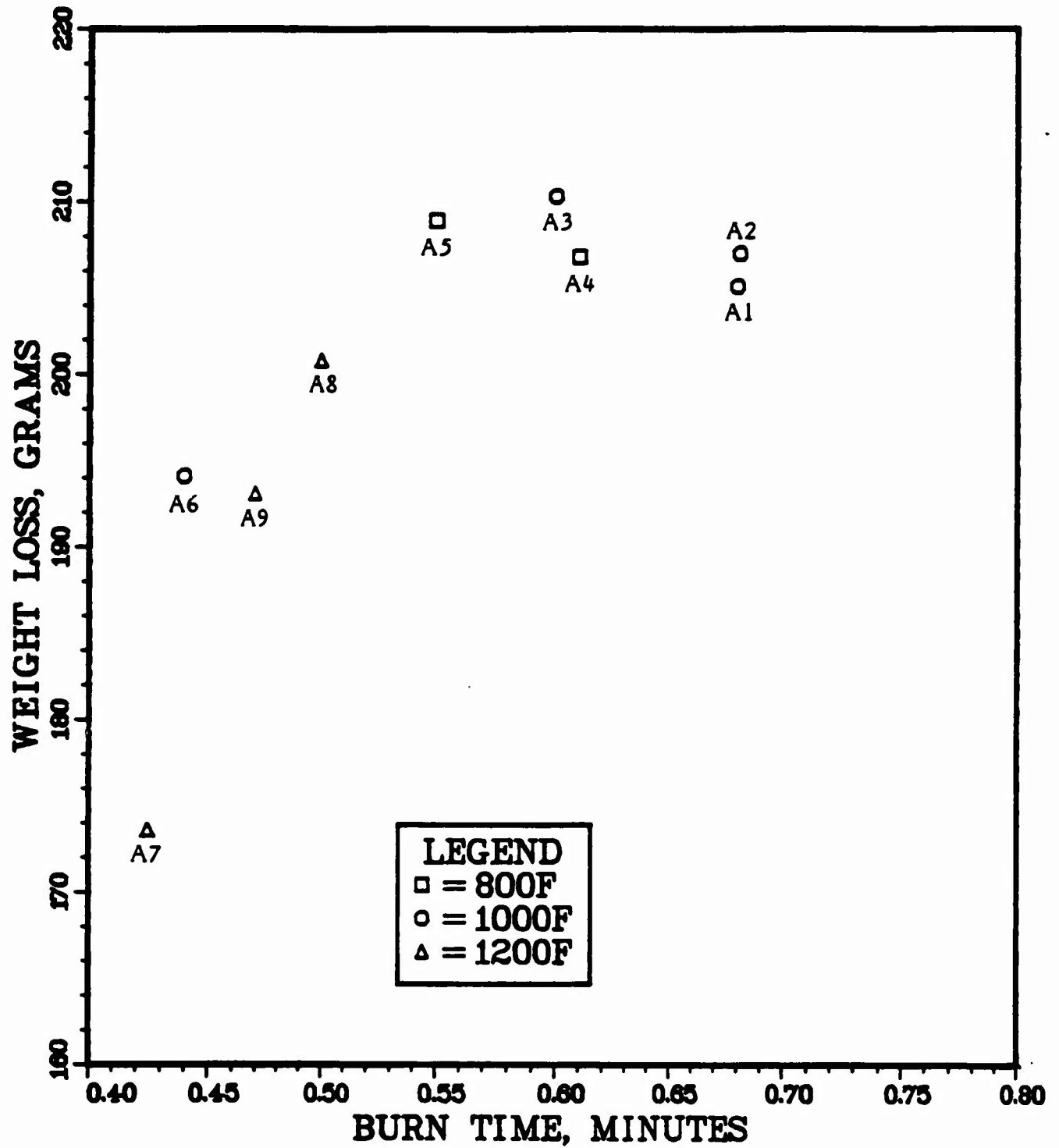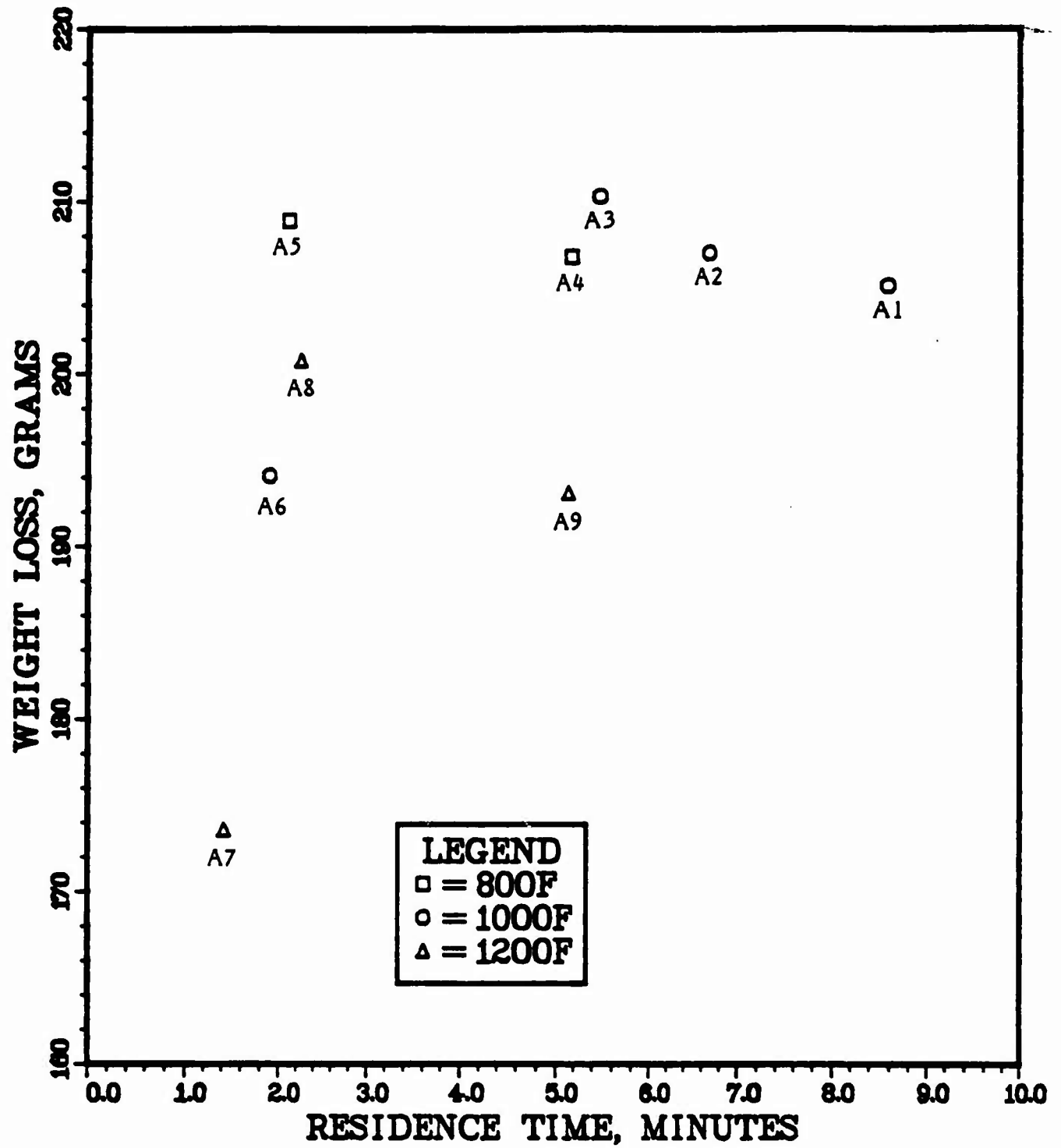
FIGURE 18. WEIGHT LOSS VS. BURN TIME

FIGURE 19. WEIGHT LOSS VS. RESIDENCE TIME

6.5 CHEMICAL ANALYSIS

6.5.1 Venturi Scrubber Brine Samples

Scrubber brine samples were taken during operation and were identified by the time and date the sample was taken. The samples were taken from the venturi scrubber recirculation tank.

Each brine sample was chemically analyzed for sulfate ($SO_4^=$) and chloride (Cl^-) concentration. The pH of each sample was measured with an electronic pH meter using a standard glass electrode. The sulfate concentration was determined by titration of a 10 ml quantity of sample with a standard solution of barium perchlorate in the presence of thorin indicator to show end point (reference, Federal Register, Vol 42, No. 16, pages 41782-41785). The chloride concentration was determined gravimetrically by applying the silver nitrate precipitation method (reference, Handbook of Anion Determinations, Butterworth, pages 295, 296). The sulfate and chloride concentrations, and the pH of the scrubber brine samples are tabulated in Table 8.

The concentrations in the scrubber brine are dependent on the operating conditions of the incinerator complex system and the period of time of continuous smoke grenade feed at the time the sample was taken. The venturi scrubber recirculates the scrubbing brine and maintains liquid level by adding make-up water. The blowdown rate is maintained at 15 gpm and the amount of scrubbing brine is maintained at 100 gallons. The brine sample taken at 1005 on December 9, 1981 is a sample of the scrubber water before any smoke grenades had been incinerated in the deactivation furnace. The last sample taken at the end of each day's test were taken after smoke grenade feed had been stopped. An explanation for the high chloride concentration remaining in the scrubber brine is the salting of particulate in the long run of ducting from the deactivation furnace to the afterburner.

TABLE 8. SUMMARY OF pH, SULFATE AND CHLORIDE CONCENTRATIONS OF
VENTURI SCRUBBER SUMP WATER, AT THE PINE BLUFF ARSENAL -
INCINERATOR COMPLEX

	Run 01 December 7, 1981				Run 02 December 8, 1981			Run 03 December 9, 1981			
	1130	1152	1409	1645	1135	1525	1705	1005	1422	1608(a)	1801
pH,	3.4	3.2	3.5	3.2	2.5	2.6	3.7	6.1	2.4	2.2	3.3
SO_4^-, ppm	196	162	147	0	225	142	0	0	108	157	0
Cl^-, ppm	153	144	173	146	151	134	158	47	114	153	250

(a) Temperature measured by thermocouple was 140 F.

6.5.2 Particulate Analysis

The particulate collected at each of the sampling points for particulate loading was analyzed for metals and organic content. The particulate analysis was combined with analysis of the impinger samples to give total metal emissions and these results are presented in Table 9. The heavy metal emissions are below any Federal or state standard. A complete evaluation of the heavy metal emissions are detailed in the USAEHA report, Reference 5.

Lead, zinc, chromium and nickel probably originate from the terneplate shell, fuzes and the paint on the canisters. The sodium and potassium originate from the pyromix.

Table 10 compares the three incineration tests in terms of the emissions of particulate matter per M18 smoke grenade and also includes the emissions of particulate determined during Task 7 at Tooele. The emissions measurements from Task 7 were taken from the exhaust duct of an APE 1236 deactivation furnace at Tooele. The differences between the emissions appears to be within experimental error.

7. INTERPRETATION OF TEST RESULTS

7.1 DEACTIVATION FURNACE

An evident result of the feeding of 4 M18 smoke grenades every thirty seconds is an increase in the exhaust gas temperature and the increase in the fourth retort skin temperature. This temperature increase is illustrated in Figure 11. The temperature increases were enhanced as a result of the 3rd and 4th retort sections being insulated. If the insulation were not present the heat losses would have kept the retort skin temperature from achieving the temperature it did while incinerating M18 smoke grenades. At a skin temperature of 1000 F, the heat losses from a single retort section would be approximately 0.5 million Btu/hour. This heat loss is much larger than the heat liberated from the incineration of M18 smoke grenades so long as the dye does not burn in the deactivation furnace, resulting in sufficient heat losses to prevent high retort skin temperatures.

TABLE 9. ELEMENTAL ANALYSIS OF EMISSIONS DURING
INCINERATION OF M18 SMOKE GRENADES

Element	Run 1		Run 2		Run 3	
	Quench	Stack	Quench	Stack	Quench	Stack
Pb (mg/m^3)	1.13	0.27	1.55	0.66	0.96	0.40
Zn (mg/m^3)	14.51	2.26	5.81	2.68	3.01	2.24
Cr (mg/m^3)	0.03	0.02	0.01	0.01	ND	ND
Ni (mg/m^3)	0.18	0.02	0.02	0.01	ND	0.02
Na (mg/m^3)	390.2	ND*	ND	ND	ND	ND
K (mg/m^3)	64.25	10.68	71.76	22.01	44.48	23.82

* ND - None Detected

TABLE 10. ELEMENTAL EMISSIONS PER M18 SMOKE GRENADE

EMISSION PER GRENADE (mg)

Element	Run 1		Run 2		Run 3		Task 7 (To Afterburner)	
	Quench	Stack	Quench	Stack	Quench	Stack	Fused Grenades	Unfused Grenades
K	935.	455.	1418.	652.	1065.	780.	1700.	1200.
Na	5581.	ND*	ND	ND	ND	ND	680.	230.
Pb	16.45	11.51	30.64	19.55	22.99	13.09	17.0	1.2
Zn	211.24	96.31	114.83	79.39	72.09	73.31	68.0	0.46
Cr	0.44	0.85	0.20	0.30	ND	ND	ND	ND
Ni	2.62	0.85	0.40	0.30	ND	0.65	68.0	0.23

* ND - None Detected

The APE 1236 deactivation furnace is constructed from WC-9 low alloy steel. The yield strength of this steel drastically reduces above 1000 F. This reduction in yield strength significantly affects the capability of the furnace to withstand impulsive loading due to any low order or high order detonations. Service life of the retort would be reduced to a great extent, if the retort is allowed to operate at temperatures higher than 1000 F.

For operation with BZ munitions, which are much more likely to liberate greater amounts of heat as a result of BZ vapor burning in the deactivation furnace, it may be required to jacket the retort section or sections where the high levels of heat are liberated to provide additional cooling with air passage through the jacket. Alternatively, the overall gas flow through the furnace can be increased to carry the heat generated out of the furnace. This alternative could require an increase in the size of the pollution control system if large amounts of dilution air are required to reduce deactivation furnace temperatures.

Furnace temperature is controlled at the burner end to assure that the solid residue coming out of the furnace is heated to the desired detoxification temperature. If the control point is relocated to the exhaust end, then the burner end may get below the desired detoxification temperature. Moreover, the controller would have rapid oscillations due to noncontinous heat generation of the irregular munition feed. There are other complications with control located at the exhaust end. When the munition burns liberating heat, the resultant rise in exhaust gas temperature would cause the controller to reduce fuel to the burner. This reduction in burner fuel reduces the total gas flow through the furnace possibly resulting in a temperature increase instead of the desired reduction in temperature. This would lead to instability in the control of the furnace temperature and the temperatures of the gases and the retort wall may reach damaging levels. To eliminate high exhaust gas temperatures the exhaust gas temperature can be controlled by controlling the amount of infiltration air at the munition feed port on the furnace.

7.2 POLLUTION CONTROL SYSTEM

The particulate and gaseous emissions determined after the quench during these tests are below statuatory emission limits, which casts doubt on whether or not a pollution control system is necessary. However, the potential emissions from the drum

inventory are unknown and a system to capture BZ in the event of a system upset would be desirable. From this reasoning it is felt that a pollution control system is justified. Also, the use of a pollution control system provides an additional safety factor in meeting emission limits.

Based on the liquid to gas ratio of approximately 30 gallons per 1000 acf observed at PBA and using a throat velocity of 190 ft/sec, an efficiency of SO_2 removal was calculated to 99.7 percent (Ref. 4) so long as sufficient H_2O_2 is present in the scrubbing liquid to oxidize the SO_2 instantaneously. With this efficiency, a packed bed scrubber would not be needed for the BZ facility, even if SO_2 emissions were a concern.

Following the venturi is the mist eliminator(s), induced draft (ID) fan and the stack. The problem of condensate following the mist eliminator can be addressed two ways to reduce the corrosion caused by condensate. The first is to reheat the gas, which will result in avoiding downstream condensation and corrosion, avoid a visible plume, and enhance plume rise and dispersion of pollutants. The second way is to construct the ID fan, ducting and stack with materials that are corrosion resistant. The method currently used at CAMDS is the second one and the material is epoxy coated steel. This appears to be the simplest route since reheat would require an energy source to reheat the flue gas.

The mist eliminator can be either of the fiber type or an electrostatic precipitator, both of which are capable of removing submicron particles. The fiber type, such as the Brinks mist-eliminator used at CAMDS, will be more cost effective and should not have plugging problems because of the low amounts of particulates contained in the flue gas. If there were large amounts of particulates, then the electrostatic precipitator might be a better choice.

One recommended PCS, based on the test results for the BZ facility, can consist of a quench, variable throat venturi scrubber, mist eliminator(s), ID fan and stack. The quench would be constructed of a high temperature alloy and the venturi scrubber of FRP. The quench water flow would have to be backed up by an emergency quench tank to protect the scrubber from high temperatures in the event of a stop in water flow to the quench. The mist-eliminator would be a fiber type which can be proceded by baffles to eliminate larger sized mist and particulate to reduce loading on the fiber. The ducting from the mist eliminator to the ID fan and the stack can be constructed of FRP. The ID fan can be FRP, or epoxy coated steel or a combination of the two.

Another recommended PCS based on the test results for the BZ facility can consist of a gas cooling device such as a quench, heat exchanger or dilution air, baghouse, ID fan and stack. This system would eliminate a liquid effluent.

7.3 LIQUID WASTE STREAM

The liquid waste stream from the pollution control system would be generated from the blowdown of scrubber liquor from the venturi scrubber. The waste stream will be composed of water, H_2O_2, H_2SO_4, HCl, HNO_3, Cl_2 and particulate. The approximate composition of the blowdown based on 1000 gallons per day and the average emissions and flowrates measured for these tests is as follows:

	Wt. %
H_2O	97.2
H_2SO_4	1.9
H_2O_2	0.3
HCl	0.1
Cl_2	0.05
HNO_3	0.2
Solids	0.25

The scrubber liquor blowdown will be collected in storage tanks to be verified free of BZ before discharge to the waste water treatment plant. Any blowdown containing BZ will be passed through ion exchange resin to remove the BZ before discharge.

8. CONCLUSIONS

The following conclusions were reached from the incineration of M18 smoke grenades at the Incineration Complex at PBA.

1) A burner temperature of 800 F and residence time of 5 minutes in an APE 1236 deactivation furnace was sufficient to incinerate M18 smoke grenades. The remaining char left in the canister from the incineration of Green IV smoke grenades showed no indications of melting even when subjected to a burner temperature of 1200 F and residence time of 5 minutes in an APE 1236.

2) The heat released from the incineration of 8 M18 smoke grenades per minute resulted in high skin temperatures in the two insulated retort sections of the APE 1236, but indications are that heat losses would be sufficient to reduce the skin temperature to acceptable levels if the sections were uninsulated.

3) Particulate emissions measured after the afterburner operating at 1800 F and the quench averaged 4.85 milligrams per M18 smoke grenade. The total metal emissions measured after the quench were Pb, 23.36 mg/grenade; Zn, 132.72 mg/grenade; Cr, 0.21 mg/grenade; Ni, 1.01mg/grenade; Na, 1860 mg/grenade; K, 1140 mg/grenade.

4) The venturi scrubber reduced particulate emissions by 56 percent at a pressure drop of 20 inches of water across the venturi and 38 percent at 14 inches.

5) The average noxious gas emissions measured after the quench were SO_2, 411 ppm (21.45 g/grenade); HCl, 85 ppm (1.58 g/grenade); Cl_2 19 ppm (0.38 g/grenade); NO_x, 40 ppm (0.98 g/grenade).

6) The Incineration Complex at PBA is a viable process for the disposal of M18 smoke grenades.

7) The emissions measured following the quench during these tests were all below any applicable state air standards.

9. RECOMMENDATIONS

- No additional testing regarding the emissions generated from pyrotechnic munitions are required for the design of the BZ demilitarization facility

- To consider a baghouse as the pollution control device for the BZ demilitarization facility based on the low amounts of emissions measured during these tests.

10. REFERENCES

1) "Behavior of Pyrotechnic Mixtures During Incineration", Final Task 7 Report prepared by Battelle's Columbus Laboratories for the Department of the Army, Toxic and Hazardous Materials Agency, Contract DAAK11-78-C-0096, January 1980.

2) "Incineration/Detonation Studies", Final Task 9 Report Prepared by Battelle's Columbus Laboratories for the Department of the Army, Toxic and Hazardous Materials Agency, Contract DAAK11-78-C-0096, August 1981

3) "High Temperature Corrosion Study with BZ Pyrotechnic Munition Residues", prepared by Battelle's Columbus Laboratories for the Department of the Army, Toxic and Hazardous Materials Agency, ARO Scientific Services Program DO 1873 (TCN-81-149), October, 1981.

4) "Preliminary Engineering Design of System Concept No. 3 for Demilitarizing the BZ Item/Munition Inventory", Final Task 5 Report prepared by Battelle's Columbus Laboratories for the Department of the Army, Toxic and Hazardous Materials Agency, Contract DAAK11-78-C-0096, October 1980.

5) "Incineration of M18 Smoke Grenades as an Agent BZ Simulant", Stationary Air Pollution Source Assessment No. 42-21-1239-82, United States Army Environmental Hygiene Agency, December 1981.

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APPENDIX I

TEST PLAN

TEST PLAN OF
SIMULATED BZ MUNITIONS
IN THE DEACTIVATION FURNACE
AT PINE BLUFF ARSENAL

to

UNITED STATES ARMY
Toxic and Hazardous Materials Agency

November 10, 1981

by

D.W. Folsom

BATTELLE
Columbus Laboratories
505 King Avenue
Columbus, Ohio 43201

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I. INTRODUCTION

The proposed conceptual process system developed to dispose of BZ-containing munitions requires knowledge for design that is not now available.[1] Unknown areas that involve the rotary kiln destruction furnace system and the pollution control system will be explored in a series of tests described here to be performed at Pine Bluff Arsenal (PBA). These tests will be conducted on PBA's Incineration Complex (consisting of an APE 1236 DEAC furnace with afterburner and venturi scrubber) using M18 smoke grenades as simulants for the BZ munitions. Given the similar pyrotechnic composition of the M18 smoke grenade and the BZ munitions, and the presumably similar behavioral characteristics in a thermal environment, information on the behavior of the smoke grenades in the DEAC may be qualitatively extrapolatable to the BZ munitions and used in the design of the furnaces and flue gas control equipment. The subject of this test plan is thus, to fill these unknown areas to permit the design of the destruction furnace system and pollution control system for the BZ demil facility.

II. OBJECTIVES

The overall objectives of the proposed M18 grenade incineration tests are to:

1. Determine operating temperature and residence time in the DEAC

2. Determine the effect of a feed rate of eight grenades per minute on the control of the DEAC furnace temperature

3. Determine the composition, mass, and size of particulates generated by the incineration of grenades in the DEAC

4. Determine the effectiveness of the venturi scrubber in controlling particulate emissions from grenade incineration

5. Determine gaseous emissions from the afterburner.

Objective 1

Determine operating temperature and residence time of the smoke grenades in the APE 1236 DEAC.

Background. Based on previous test results[2], an inerted smoke grenade will take longer to ignite at a given DEAC furnace temperature and will burn slower than an uninerted grenade. This feature of inerted grenades, which has been addressed at length in a previous report[2], is desirable since longer grenade (and BZ munition) burn times will reduce gas surges to the afterburner. However, the longer burn time results in longer residence times required in the DEAC furnace. The longer residence time may result in the munition achieving a higher temperature than desired, causing the highly corrosive char to extrude from the munition onto the internals of the DEAC furnace. Ideally the grenade (munitions) should be processed through the DEAC furnace at a combination of furnace temperature and munition residence time to promote complete volatilization of the grenade (munition) fill without the char reaching its eutectic melting point. These factors will have an impact on the design of the furnace and flue gas pollution control equipment.

Technical Approach. To determine the most favorable operating conditions of the retort furnace that will promote maximum vaporization of the grenade fill without melting the remaining char, the furnace will be operated at various combinations of furnace temperatures and residence times. Eight individual tests will be made, each utilizing ten grenades. At each of the various test conditions the time to ignition and burn time of each of the ten grenades will be monitored. As the grenades are discharged from the furnace they will be monitored for colored smoke, an indication of incomplete vaporization of the grenade fill. Also the weight and appearance/condition of the char remaining in the processed grenades will be determined. The test matrix is discussed in detail in Section IV.

Objective 2

Determine the effect of a feed rate of eight grenades per minute on the control of the furnace temperature.

Background. During actual demil operations, more than one BZ munition will be present in the destruction furnace at a given time. Since BZ munitions and M18's have essentially the same pyro-mix, and the mix has a high heat value, they will contribute heat to the furnace. The processing of multiple munitions will have an impact on the furnace temperatures, flue gas flow rate, furnace pressure, and the burner fuel flow required to maintain the set operating temperature. These effects of multiple munitions functioning in the destruction furnace will have to be determined to design the destruction furnace system.

An M18 smoke grenade is approximately the same size as an M6 or M7 BZ submunition. An M138 BZ submunition contains four M7 submunitions so, four M18 grenades will simulate an M138. Current planning[1] calls for 12 M43 or 24 M44 BZ munitions to be processed per day. This averages out to 8.4 M6's per minute (7.6 M7's per minute) based on a 6-hour processing day.

Technical Approach. Based on feeding 8.4 M6's per minute, 84 oz/min of BZ pyromix (or 7.6 M7's/min, 91 oz/min), this test will process eight M18's per minute, 92 oz/min, to simulate M138 submunitions. Four M18's, three without fuzes, will be fed to the furnace every 30 seconds for a total of eight M18's per minute, the equivalent of two M138's per minute. This feed rate of four every 30 seconds will be a worst case situation for heat load, gas pressure, and flue gas flow rate and is similar to the functioning of an M138 in which four M7's function simultaneously.

These tests will be conducted with four colors of M18 grenades (red, yellow, violet, green)*. The M18's for this and the following objectives will be uninerted to provide a worst case situation regarding heat load, particulates, and gas pressure surges. Due to the amount of air infiltration into the furnace, the gas pressure surges should not be evident as long as there is a negative pressure in the furnace in relation with its surroundings.

Parameters to be monitored during the test include furnace burner and exhaust temperatures, retort skin temperatures before burning grenades and during the burning, air and fuel flows to the burner, and flue gas flow to the afterburner.

Objective 3

Determine the composition, mass and size of the particulate generated by the incineration of grenades in the deactivation furnace.

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* Due to insufficient quantities of any one color of grenade, a variety of colors was selected.

Background. Previous tests on the incineration of M18 smoke grenades in an APE 1236 furnace resulted in a high particulate loading in the flue gas because of the difficulty in burning the "smoke" from the incinerated grenades.[2] Up to 17 grams of particulate carbon and 2.4 grams of alkali metals were emitted per incinerated grenade.

The presence of alkali metal salts could cause severe corrosion problems in hot components downstream from the incinerator. Lead and tin containing particulates were present in the stack when incinerating unfuzed grenades. Nickel, copper, zinc, lead, and tin containing particulates were considerably increased when incinerating grenades with fuzes as compared to defuzed grenades.

It is necessary to know the nature and size of the particulates generated in order to perform an engineering design for a venturi scrubber to reduce the emissions below the applicable regulations. Also, the concentration of trace constituents such as chlorides, heavy metals, and organics in the flue gas can impact on the selection of construction materials for the full scale scrubber system and on the utilization of peroxide additive.

Technical Approach. The test is discussed in detail in Section IV. The particulate loading and particle size distribution will be measured in the duct between the quench tower and the venturi where the flue gas is at a temperature of about 700 F (Port 2, Figure 1). At this location, some of the volatile materials should condense to form an aerosol. The particulate loading and particle size distribution will also be measured in the stack where the flue gas is at a temperature of about 200 F (Port 5). Taking particulate measurements at the two specified locations will permit the acquisition of the maximum reasonable test data and will provide information for Objective 4. Of course, this test program cannot address the knowledge gap related to the nature and size of BZ emissions from the afterburner (BZ incinerator) as compared to the nature and size of emissions generated from the incineration of M18 grenades. To check the amount of particulate that is dye, that would not be present in BZ emissions (if there is evidence of dye present in the particulate), a carbon and hydrogen analysis of the particulates to determine the amount of dye will be performed. Note that the dyes are mostly condensed ring species and are likely to be more difficult to ignite and burn than BZ.
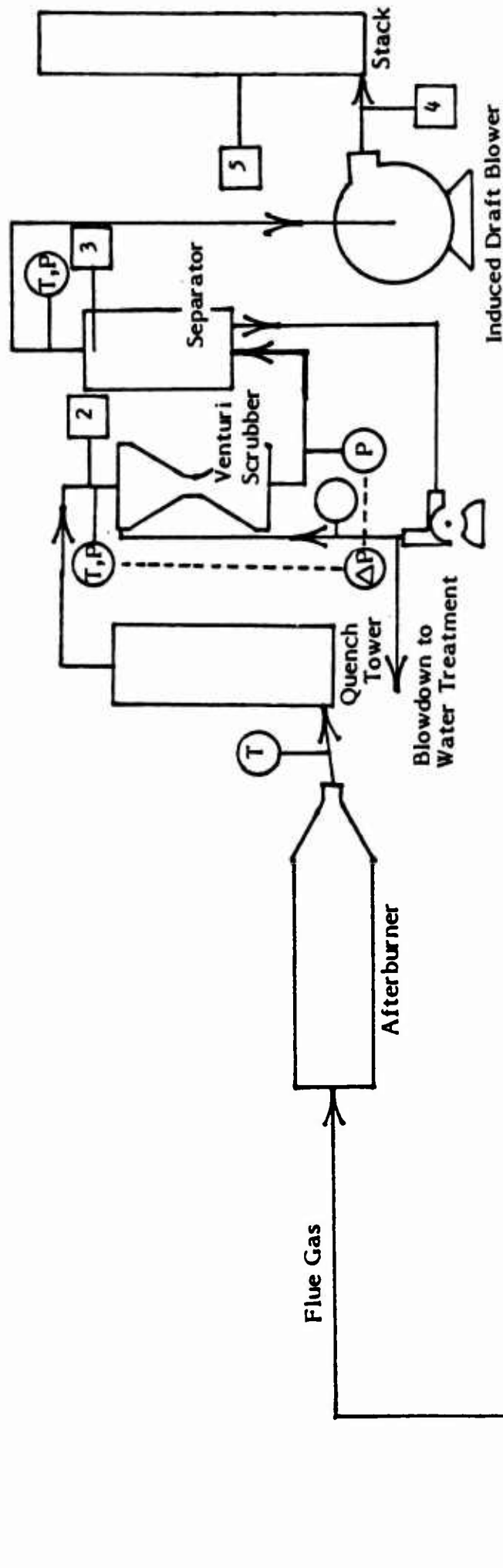
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Sample Points

1. BCL, SO_2 and O_2
2. USAEHA, Particulate size and loading
   O_2, N_2, CO, CO_2, SO_2, SO_3, NO_2,
   NO_x Moisture
3. BCL, Acid Mist size and concentration
4. MRI, BZ Alarm Test
5. USAEHA, Particulate Size and Loading
   O_2, N_2, CO, CO_2, SO_2, SO_3, NO_2,
   NO_x Moisture

□ — Sample Points

○ — Instrumentation Points

F - Flow Meter
P - Pressure Gauge
T - Thermocouple or Contact Pyrometer

Stack

Induced Draft Blower

Separator

Venturi Scrubber

Quench Tower

Blowdown to Water Treatment

Afterburner

Flue Gas

Fuel and Air

Processed Munitions

Deactivation Furnace

Munitions
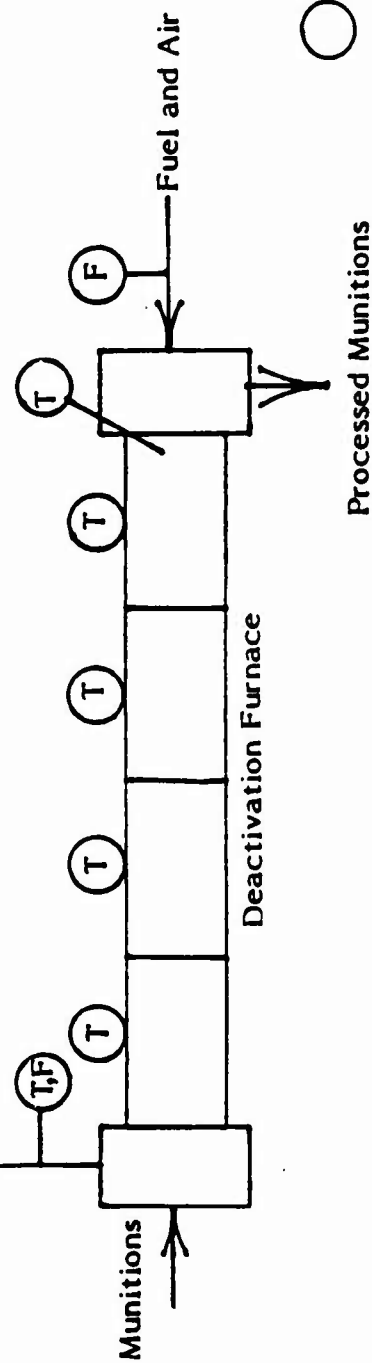
FIGURE 1. SYSTEM SCHEMATIC

The particulate mass loading will be determined by EPA Method 5 procedures as described in the Federal Register, Volume 42, No. 16, pages 41776-41782. A sample is extracted isokinetically from the gas stream using a nozzle and a heated glass probe. Particulates are collected on a heated glass fiber filter at the probe exit. The probe and filter temperatures are maintained at about 250 F. Following the test, particulates are recovered from the nozzle and probe which, along with the filter catch, comprise the mass of particulate material collected. Gas volume sampled during the test is measured with a dry test meter. Test results are normally reported as mass loading in grains/dry scf (standards conditions are 70 F, 760 mm Hg.) EPA Methods 2, 3 and 4 will be employed along with the Method 5 measurements to determine gas velocity (volumetric flow), gas composition (CO_2, CO, O_2) and moisture, respectively. It may be desirable to use solvent-containing impingers at the tail end of the Method 5 sampling trains to detect any unusual components in the vapor phase of the flue gas.

Particle mass distribution measurements will be performed with a cascade impactor such as the Andersen Mark III using a sample that will be extracted isokinetically from the gas stream. The impactor fractionates the particulates in ranges based on aerodynamic size. The Anderson impactor has 10 stages which provide 50 percent cut diameters over the range of about 0.52 to 13.4 μm under normal operating conditions. Particulates are collected on tared glass fiber filter media. The filter medium on each stage is weighed following sample collection to obtain the mass in each particle size cut. A micro-balance (sensitivity of 1×10^{-6} grams) is used for the mass determinations. Captured particulates will be subjected to chemical analysis for sodium, potassium, chlorine, nickel, zinc, lead, chromium and cadmium.

Objective 4

Determine the effectiveness of the venturi scrubber in controlling particulate emissions from grenade incineration.

Background. Maintaining high pressure drops across a venturi increases the scrubbing efficiency, particularly of smaller particles, at the expense of higher power requirements and higher liquid flow rates. It is therefore, important to determine the relationship between the pressure drop across a venturi scrubber and the scrubbing efficiency of particulates generated from the incineration of munitions.

Technical Approach. These tests will be conducted simultaneously along with Objectives 2 through 5. Furnace temperature and residence time will be those found to be optimal during Objective 1. The venturi efficiency will be determined from the particulate loading/sizing information taken at sampling ports 1 and 2 (refer to Figure 1) taken as part of Objective 3.

For the first of the two tests, the pressure drop across the venturi will be 20 inches of water. If this setting is successful at achieving 0.6 grains per cubic feet* or below, the pressure drop will be reduced to a new setting based on the efficiency determined from the first test. Otherwise, the pressure drop will be increased. The second test will be a repeat of the first test at the newly determined pressure drop.

The tests at the two pressure drops will last 3 hours each. This is to allow the system to stabilize and to collect sufficient particulate (USAEHA has determined that sample point 1 needs at least a 2 hour test: 15 minutes stabilization, 1 hour 36 minutes sampling, 15 minutes sampler change out).

Objective 5

Determine gaseous emissions from the afterburner.

Background. The concentrations of gaseous emissions leaving the afterburner (gases generated from the incineration of pyro-mix munitions) are needed for the design of an air pollution control system.

Technical Approach. At sampling points 2 and 5 applicable EPA methods will be utilized to determine CO_2, CO, N_2, O_2, SO_2, SO_x, NO_2, NO_x, and moisture.

III. FACILITIES AND EQUIPMENT

Facilities

The tests will be conducted at PBA's Incineration Complex. The equipment in this complex to be used for these tests will consist of:

- APE 1236 deactivation furnace
- Afterburner
- Quench
- Venturi scrubber
- Induced draft fan

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* Based on AEHA Dispersion Model, NAAQS total suspended particulate increment value of 0.19 mg/m^3, and flue gas flowrate of 6000 acfm at 200 F.

To obtain meaningful data, it will be necessary to refrain from operating the grenade test chamber and the chain grate furnace, and to close the outlet damper of these two units during the entire test program. If the outlet dampers are known to leak, it is advised to blind these outlet lines.

Equipment

1. SO_2 monitor for measurement of the time to ignition and the burn time, of the M18's. The monitor should be capable of measuring up to at least 2000 ppm SO_2.

2. Two complete EPA Method 5 sampling trains with two complete sample boxes for particulate loading measurements. The particulate filter should be followed by two bubblers to detect possible volatile forms of lead and mercury that might exist in the furnace flue gas. This procedure for heavy metals is described in the IERL-RTP "Procedures Manual: Level 1 Environmental Assessment", Second Edition.

3. Mark III Andersen cascade impactors with pump and metering system for measuring particle size distributions at two sampling points.

4. O_2 analyzer to monitor the oxygen content of the flue gases at sample port 1.

5. Recorder to keep records of trends that are being monitored.

6. Various expendable materials as listed in Table 1.

IV. PROCESS VARIABLES

The tests are divided into two series:

- Determination of required deactivation furnace conditions (Objective 1)
- Determination of flue gas composition and charateristics, and venturi scrubber effectiveness in controlling flue gas emissions (Objectives 2-5).

TABLE 1. LIST OF EXPENDABLE MATERIALS

Item	Quantity/Size
M18 Smoke Grenades	2690
SO_2 Span Gas	1 Cylinder

Test procedures and data requirements for the two test series are as follows:

Objective 1

The following process varables will be investigated in the combinations shown in Table 2. The test matrix has been reduced in size to reflect the observations made at the Incinerator Complex at PBA on October 15, 1981 when eight uninerted M18 smoke grenades per minute were fed to the DEAC furnace. The first conditions were; 900 F, a retort speed setting of 4 (variable speed motor setting), and a flue gas flow rate to the afterburner of 3880 acfm. At these conditions the grenades started functioning seconds before discharging from the furnace. The conditions were changed to: 1025 F, a retort speed setting of 1.2, and flue flow rate of 1800 acfm. About half of the grenades leaving the furnace were still smoking (colored smoke) at these conditions.

For these tests, weighed, fuzed M18 green smoke grenades will be inerted with water and 0.01 percent Avirol 113 solution for 2 hours in a vertical position with their tapes removed. The grenades will be air dried (drained) in a vertical position for 22-24 hours, and weighed. This is the suggested drain time to be used during BZ munition processing. A preliminary test using 10 inerted grenades will be performed to verify that SO_2 monitoring can accurately determine time to ignition and verify that sampling system is operating correctly.

The SO_2 concentration traces for the incinerated grenades will provide the time to ignition and burn time of the grenades. Assuming that some part of the APE 1236 furnace and/or its exhaust stack will act as a well mixed system, the output concentration, c, of a tracer material (such as SO_2) released at a constant rate, q, for a time, t_1, is given by

$$c = \frac{q}{Q}(1 - e^{-\frac{Q}{V}t}), \quad 0 \le t \le t_1,$$

$$c = \frac{q}{Q}(1 - e^{-\frac{Q}{V}t})e^{-\frac{Q}{V}(t-t_1)}, \quad t_1 < t,$$

TABLE 2. TEST VARIABLES FOR DEACTIVATION FURNACE

Test No.	Burner Temperature F	Retort Drive Setting	Residence Time (Min)	Flue Flow From DEAC To Afterburner (acfm)[a]	Grenade Numbers
A-0 [b]	800	0	9.3	1800	1-10
A-1	800	0	9.3	1800	11-20
A-2	800	1	7.4	1800	21-30
A-3	1000	0	9.3	1800	31-40
A-4	1000	1	7.4	1800	41-50
A-5	1200	0	9.3	1800	51-60
A-6	1200	1	7.4	1800	61-70
A-7	1200	2	5.0	1800	71-80
A-8	1200	3	3.2	1800	81-90

(a) Use 1800 acfm as a guide, does not have to be exact

(b) Preliminary test

where Q is the total flow through the system and V is the volume of the well mixed region. If t_1 is not too large compared with $\frac{V}{Q}$, the concentration rises to a peak at t_1 and then falls. If t_1 is large compared with $\frac{V}{Q}$, then the observed concentration rises to a plateau, and again starts to fall at t_1. Based on this logic, the burning times will be assumed to be equal to the time from first appearance of SO_2 (from combustion of sulfur in the grenade) to the peak value, or to the beginning of a decline following the last of several peaks or a plateau.

The time of ignition of the M18 grenades will be estimated by determining the time between the disappearance of the grenades(s) into the furnace inlet and the first appearance of SO_2 at the sampling port in the furnace stack, and subtracting the delays associated with

- The time from disappearance of the grenade to actual fall into the furnace
- Transport of gas from the burning grenade to the sample port in the furnace stack
- Transport of gas through the sampling line and response time of the SO_2 detector/analyzer.

The residence time of the incinerated M18 grenades will be measured by the time difference between the disappearance of the grenade and its emergence from the furnace corrected for the time from dissappearance of the grenade to the actual fall into the furnace.

Data on time to ignition, burn time, residence time, and visual observations of the processed grenade will be recorded for each grenade. The grenades will be fed one at a time, so only one is in the furnace at one time. Data taken at the start and finish of each test will consist of furnace temperatures (burner end, exhaust end, skin temperatures at the four retort sections), drive setting (actual RPM will be measured), exhaust gas flowrate and temperature, and the fuel and air flowrates to the furnace burner. Ten grenades will be processed for each test for a total of 80 grenades (excluding the preliminary test). The total weight of each ten processed grenades will be also taken. Other observations to be made during this series of tests will be fluctuations in fuel and air to the furnace burner, fluctuations in the flue gas flowrate, and the temperature of the incinerated grenade as it leaves the furance by means of a

contract pyrometer or with a sharp-tipped thermocouple, that can be inserted into the char.

A test data matrix listing the results of processing grenades (ignition and burn times) at each combination of temperature and residence time will be prepared. From this matrix, the best combinations of temperature and residence time can be identified. These best conditions will be based on combinations of temperature and residence time that provide the most complete volitilization of the fill in the grenade without melting the char remaining in the grenade canister. The extent of volitilization will be determined by the total weight of the remaining char for each test. With this information, choices on actual conditions to be used in the plant can be based on minimum fuel usage, processing time desired and furnace design temperature.

The data sheet for these tests is shown in Figure 2.

Objectives 2 - 5

Objectives 2 through 5 were discussed in Section II and will be addressed simultaneously in a second series of tests. This second series will consist of two separate tests, conducted at different venturi pressure drops. The test conditions are:

- Feed rate to be 8 uninerted M18's per minute (4 every 30 seconds), mixed colors
- Residence time and temperature of furnace to be based on Objective 1 results
- Afterburner temperature 1800 F
- Flue gas flowrate to afterburner about 1800 acfm at 500 to 700 F
- Venturi scrubber 20" ΔP first test, to be determined ΔP second test.

The incinerator complex will be operated in accordance with the standard operating procedures at these conditions. The two tests will run for a steady state period of three hours each to allow particulate samples to be taken.

The incineration complex schematic (Figure 1) indicates the sample and instrumentation points and corresponding data to be gathered at each point. The gaseous emissions and particulate determinations will be made using EPA methods 2, 3, 4, and 5. From this data the venturi scrubber effectiveness will be determined since the samples are taken before and after the venturi scrubber and their difference will define the scrubber efficiency.

FIGURE 2. DATA SHEET FOR OBJECTIVE 1 TESTS

Date _____

Test ID _____

Pretest Conditions

Furnace Temperatures

    Burner End _____ F

    Exhaust End _____ F

Retort Skin Temperatures

    Burner

    1 _____ F 2 _____ F 3 _____ F 4 _____ F Exhaust

Furnace Conditions

    Burner Fuel Flowrate _____ % Scale

    Burner Air Flowrate _____ ΔP

Drive Setting _____

Time of one Revolution _____ Sec

Exhaust Flowrate _____ acfm

O_2 Reading (Exhaust) _____ %

Grenade #	Time of Feed	Time to Start of SO_2 peak Sec.	Time to decrease in SO_2 peak Sec.	Time of Discharge Min.-Sec.	Preburn Wt. Oz.	Postburn Wt. Oz.	Smoking X=Yes	Observations Comments
1								
2								
3								
4								
5								
6								
7								
8								
9								
10								

Post-test Conditions

Furnace Temperatures

    Burner End _____ F

    Exhaust End _____ F

Retort Skin Temperatures

    Burner

    1 _____ F 2 _____ F 3 _____ F 4 _____ F Exhaust

Furnace Conditions

    Burner Fuel Flowrate _____ % Scale

    Burner Air Flowrate _____ ΔP

Drive Setting _____

Time of one Revolution _____ Sec

Exhaust Flowrate _____ acfm

O_2 Reading (Exhaust) _____ %

The effect of a feed rate of eight grenades per minute (a group of four every 30 seconds) on the deactivation furnace will be determined by taking readings before, during (every ten minutes), and after the grenades are incinerated. The readings will consist of the burner temperature, exit temperature, skin temperatures, fuel and air flowrates to the burner, and the flue gas flowrate leaving the furnace. The deactivation furnace will be operated at a set exhaust temperature and the fuel flowrate controlled to maintain the set point by a proportional controller. During the test, fluctuations in the fuel, air, and flue gas flowrates, if they occur, will be checked for syncronization with the feed of four grenades.

Calculations have been made on the heat loads and gaseous emissions (Appendix A) and the results are compiled in Table 3. These results should be used only as a guide to what should be observed during these tests.

The data sheet for these two tests is Figure 3.

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TABLE 3. SUMMARY OF CALCULATIONS FOR POSSIBLE HEAT LOADS AND SO$_2$ EMISSIONS

	Heat of Combustion If Organics Burn (BTU/Hr) 8 Grenades/Min.		Heat of Combustion If Organics Do not Burn (BTU/Hr) 8 Grenades/Min.		SO$_2$ Emission (scf/grenade)	
	Higher Heating	Lower Heating	Higher Heating	Lower Heating	All Sulfur Burned	1/3 Sulfur Remaining in Char
Yellow VI	2.006×10^6	1.942×10^6	1.026×10^5	7.731×10^4	0.7219	0.4813
Violet IV	2.086×10^6	1.978×10^6	1.560×10^5	1.267×10^5	0.9507	0.6338
Red III	2.088×10^6	2.014×10^6	4.071×10^5	3.674×10^5	0.9344	0.6229
Green IV	2.084×10^6	2.011×10^6	1.423×10^5	1.206×10^5	0.8826	0.5884

Title: FIGURE 3. COMPOSITE DATA SHEET FOR OBJECTIVES 2 THROUGH 5 *

- Date ___
- Test ID ___
- Start Time (Feed) ___
- Stop Time (Feed) ___
- Total Feed: ___

Color / No table:
Green
Yellow
Violet
Red

Time (Every 10 Minutes) — row header with columns

DEACTIVATION FURNACE
- Burner Temperature, F
- Exhaust Temperature, F
- Air Flow, cfm
- Fuel Flow, cfm
- Skin Temperature, Burner, F
- Skin Temperature, 2nd, F
- Skin Temperature, 3rd, F
- Skin Temperature, Exhaust, F
- Flue Flow, cfm
- Oxygen in Flue gas, %

CONTROL ROOM
- Afterburner, Temperature, F
- Auxiliary Air Flow, cfm
- Venturi ΔP, inches of water
- Venturi Throat Opening, %

* Actual Data Sheets will be broken down by plant areas (deactivation furnace, control room)

FIGURE 3. COMPOSITE DATA SHEET FOR OBJECTIVES 2 THROUGH 5 *

Date _____   Test ID _____

Start Time (Feed) _____   Stop Time (Feed) _____   Total Feed: _____

Color	No
Green	___
Yellow	___
Violet	___
Red	___

Time (Every 10 Minutes)

DEACTIVATION FURNACE

Burner Temperature, F
Exhaust Temperature, F
Air Flow, cfm
Fuel Flow, cfm
Skin Temperature, Burner, F
Skin Temperature, 2nd, F
Skin Temperature, 3rd, F
Skin Temperature, Exhaust, F
Flue Flow, cfm
Oxygen in Flue gas, %

CONTROL ROOM

Afterburner, Temperature, F
Auxiliary Air Flow, cfm
Venturi ΔP, inches of water
Venturi Throat Opening, %

* Actual Data Sheets will be broken down by plant areas (deactivation furnace, control room)

V. TENTATIVE TEST SCHEDULE

(Task 4 - Data for Furnace/Pollution Control System)

Date	Day	Action to be Taken
11/30	Monday	Install SO_2 and O_2 sampling system on DEAC Prepare for tests
12/1	Tuesday	Heat DEAC to 800 F Inert 20 grenades for tests A1 and A2* Burn 10 uninerted grenades to test sampling system
12/2	Wednesday	Heat DEAC to 800 F Run tests A1, A2* Inert 20 grenades for tests A3 and A4
12/3	Thursday	Heat DEAC to 1000 F Run tests A3, A4 Inert 40 grenades for tests A5, A6, A7 and A8
12/4	Friday	Heat DEAC to 1200 F Run tests A5, A6, A7, A8
12/7	Monday	Analyze test results Prepare for second series of tests Heat DEAC Run 1 1/2 hour pretest
12/8	Tuesday	Run 3 hour sampling test** Take samples and data
12/9	Wednesday	Analyze data Determine new venturi setting
12/10	Thursday	Run 2nd 3 hour sampling test Take samples and data
12/11	Friday	Analyze data Clean up and remove sample systems

 * A1 through A8 tests are for Objective 1 of Test Plan

** 3 hour tests are for Objectives 2 through 5

VI. CONTINGENCIES

For the first series of tests (Objective 1) the two critical pieces of equipment are the deactivation furnace and the induced-draft fan. With these two in operation the tests could be run as long as the differential system pressure in the furnace is maintained similar to its normal operating pressure. If the furnace or fan fails to operate, the tests cannot be performed. These tests are short enough in duration that more than the scheduled tests could possibly be run if the time required to change temperature in the furnace is less than an hour. By doing this, time could be made up in case of an unexpected shutdown.

The second series of tests (Objectives 2, 3, 4 and 5) requires all equipment shown in Figure 1 to be in operation to obtain meaningful data. If some critical part of the system fails to operate, such as the afterburner, the data will be questionable. The only noncritical unit is the venturi scrubber. If the venturi fails to operate, data can still be taken that will be of value in the design of a pollution control system, but knowledge gaps will remain relating to the physical characteristics of the scrubber effluent and acid mist concentration and size distribution. One test at a set pressure drop across the venturi will provide most of the data needed for scrubber design. The second test will verify the first test and determine the effect of a change of pressure drop on scrubber effectiveness. Otherwise this effect will be assumed. Thus, the second test of the second series is not absolutely critical to the test plan, and usable data will be obtained should this second test be aborted by equipment failure.

VII. GENERAL RESPONSIBILITIES

Pine Bluff Arsenal

1. Prepare sample locations as requested by U.S. Army Environmental Hygiene Agency (USAEHA) in their protocol for stationary Air Pollution Source Assessment No. 42-21-1239-81. Provide space for the USAEHA lab trailer. Prepare sample location and provide support requested by MRI.

2. Modify preventuri duct for noncyclonic flow.

3. Provide labor to install measuring devices on deactivation furnace.

4. Operate the test facility. The entire incinerator complex must be dedicated to this program during these tests.

5. Provide smoke grenades.

6. Fill out data sheets.

7. Provide safety requirements/equipment for handling suspected carcinogens (smoke dyes).

U.S. Army Environmental Hygiene Agency

1. Analyze the exhaust gas at two locations for the materials and gas listed in this test plan (Objective #2-5).

2. Do the metals analysis on the particulate (Na, K, Ni, Zn, Pb and Cd), also chloride.

3. Do total carbon and hydrogen analysis on the particulate to determine the amount of dye.

U.S. Army Toxic and Hazardous Materials Agency

Coordinate the overall test program.

Midwest Research Institute

Evaluate interferences or operating problems caused by BZ alarm operation on an actual furnace exhaust.

Battelle Columbus Laboratories

1. Prepare test plan, provide onsite technical support and prepare final report.

2. Identify location of pressure tap and identify equipment to be used to measure ΔP at the venturi. Specify venturi set point of ΔP for the initial test for Objectives 2-5.

3. Determine any modifications required to insure noncyclonic flow at the USAEHA sampling locations. Design and fabricate required modifications and deliver to PBA for installation.

4. Verify the capabilities of the system to burn eight grenades/minutes without exceeding allowable emission limits.

5. Provide sampling equipment for burn time and time to ignition of M18 smoke grenades.

6. Provide sampling equipment for acid gas measurements at the venturi outlet.

7. Be in charge and assume technical responsibility for the test and prepare test report.

VIII. SPECIAL SAFETY CRITERIA

Test site facilities and equipment and their operation will comply with Pine Bluff Arsenal's safety regulations and Standing Operating Procedures. Protective masks to prevent exposure to SO_2 and trace quantities of dye from M18 smoke grenades are to be available for test personnel during testings. The masks are to be worn in the immediate area where emissions of smoke are observed or SO_2 odor detected.

REFERENCES

(1) Ballantyne, W.E., "Engineering and Technical Support of Agent BZ Disposal Processes; Task 5 - Preliminary Engineering Design of System Concept No. 3 for Demilitarizing the BZ Item/Munition Inventory", Battelle's Columbus Laboratories Final Task Report (October 1980).

(2) Weller, A.E. and Mezey, E.J., "Engineering and Technical Support of Agent BZ Disposal Processes; Task 7 - Behavior of Pyrotechnic Mixtures During Incineration", Battelle's Columbus Laboratories Final Task Report DRXTH-IS-80051 (January 1980).

APPENDIX A

CALCULATIONS

Calculations

The following calculations are to estimate the amount of heat released when an M18 smoke grenade functions in the deactivation furnace. The heat released consists of the pyromix burning and the burning of the smoke dye in the deactivation furnace. The calculations are provided for each case, whether the smoke dye burns in the furnace or not.

The second set of calculations is a mass balance around the deactivation furnace to estimate the amount of dilution air that enters the furnace while in operation. These calculations are also done for each case, whether or not the smoke dyes burn in the furnace.

The final set of calculations are estimates of the amount of SO_2 that may be released per grenade during incineration. The first of the calculations are for all the sulfur being converted to SO_2, the others reflect previous test results[2] in which 1/3 of the sulfur remains with the char.

COMPOSITION OF <u>YELLOW VI</u> SMOKE GRENADE

Substance	Weight Fraction	Molecular Wt.	Moles/g mix
$C_{17}H_{10}O$	0.250	230.2	10.860×10^{-4}
$C_{24}H_{12}O_2$	0.135	332.4	4.061×10^{-4}
$NaHCO_3$	0.330	84.0	39.286×10^{-4}
$KClO_3$	0.200	122.6	16.313×10^{-4}
S	0.085	32.1	26.480×10^{-4}

Gaseous Products

CO_2 from combustion	2.821 centimoles/g mix
CO_2 from $NaHCO_3$	0.196 centimoles/g mix
H_2O from combustion	0.787 centimoles/g mix
H_2O from $NaHCO_3$	0.196 centimoles/g mix
SO_2	<u>0.265 centimoles/g mix</u>
	4.265 centimoles/g mix

Reactants

Substance	Quantity Centimoles/g mix	Heat of Formation Kcal/mal	Kcal/g mix
Combustable Carbon	2.821	0	0
Available Hydrogen	1.194	0	0
Combined Water	0.190	-68.317	-0.130
Sulfur	0.265	0	0
$NaHCO_3$	0.393	-226	-0.888
$KClO_3$	0.163	-93.5	<u>-0.152</u>
		Total	-1.170

<u>Products</u>

Substance	Quantity Centimoles/g mix	Heat of Formation Kcal /mol	Kcal/g mix
CO_2	3.017	-94.052	-2.838
H_2O	0.983	-68.317	-0.672
SO_2	0.265	-70.94	-0.188
KCl	0.163	-104.35	-0.170
Na_2CO_3	0.196	-269.46	-0.529
		Total	-4.397

Higher Heat of Combustion $= -(-4.397 + 1.170) = 3.227 \dfrac{Kcal}{g\ mix}$

$$= 5814 \dfrac{BTU}{lb}$$

Lower Heat of Combustion $= 3.227 - (9.83 \times 10^{-3})(10.53) = 3.124 \dfrac{Kcal}{g\ mix}$

$$= 5628 \dfrac{BTU}{lb}$$

HEAT OF COMBUSTION OF <u>YELLOW VI</u> (if dyes don't burn)

Reactants

Substance	Quantity Centimoles/g mix	Heat of Formation Kcal/mol	Kcal/g mix
Combustable Carbon	2.821	0	0
Available Hydrogen	1.194	0	0
Combined H_2O	0.190	-68.317	-0.130
Sulfur	0.265	0	0
$NaHCO_3$	0.393	-226	-0.888
$KClO_3$	0.163	-93.5	-0.152
		Total	-1.170

Products

Substance	Quantity Centimoles/g mix	Heat of Formation Kcal/mol	Kcal/g mix
Carbon	2.821	0	0
Hydrogen	1.194	0	0
Water	0.386	-68.317	-0.264
SO_2	0.265	-70.94	-0.188
KCl	0.163	-104.35	-0.170
Na_2CO_3	0.196	-269.46	-0.529
CO_2	0.196	-94.052	-0.184
		Total	-1.335

Higher Heat of Combustion $= 0.165 \dfrac{Kcal}{g} = 297.3 \dfrac{BTU}{lb}$

Lower Heat of Combustion $= 0.124 \dfrac{Kcal}{g} = 224.1 \dfrac{BTU}{lb}$

HEAT RELEASE FROM 8 GRENADES/MIN.

$$(8 \frac{Grenades}{MIN.}) \; (\frac{11.503 oz.}{Grenade}) \; (\frac{1 \; lb}{16 \; oz.}) \; (\frac{60 \; min}{1 \; hr}) = 345 \frac{lb}{hr.}$$

1) Smoke Dye Burning (from data pg. 2)

Higher heating value

$$(345 \frac{lb}{hr.}) \; (5814 \frac{BTU}{lb}) = 2.006 \times 10^6 \; \frac{BTU}{hr.}$$

Lower heating value

$$(345 \frac{lb}{hr}) \; (5628 \frac{BTU}{lb}) = 1.942 \times 10^6 \; \frac{BTU}{hr.}$$

2) Smoke Dye Not Burning (from data pg. 3)

Higher heating value

$$(345 \frac{lb}{hr}) \; (297.3 \frac{BTU}{lb}) = 1.026 \times 10^5 \; \frac{BTU}{hr}$$

Lower heating value

$$(345 \frac{lb}{hr}) \; (224.1 \frac{BTU}{lb}) = 7.731 \times 10^4 \; \frac{BTU}{hr}$$

COMPOSITION OF VIOLET IV SMOKE GRENADE

Substance	Weight Fraction	Molecular Wt.	Moles/g mix
$C_{14}H_{20}N_2O_2$	0.336	248.3	13.53×10^{-4}
$C_{15}H_{11}NO_2$	0.084	237	3.54×10^{-4}
$NaHCO_3$	0.18	84	21.43×10^{-4}
$KClO_3$	0.288	122.6	23.49×10^{-4}
S	0.112	32.1	34.89×10^{-4}

Gaseous Products

CO_2 from combustion	2.425 centimoles/g mix
CO_2 from $NaHCO_3$	0.107 centimoles/g mix
H_2O from Combustion	1.548 centimoles/g mix
H_2O from $NaHCO_3$	0.107 centimoles/g mix
SO_2	0.349 centimoles/g mix
N_2	0.153 centimoles/g mix
	4.689 centimoles/g mix

Reactants

Substance	Quantity Centimoles/g mix	Heat of Formation Kcal/mol	Kcal/g mix
Combustable C	2.425	0	0
Available H	2.413	0	0
Combined H_2O	0.341	-68.317	-0.233
Combined N_2	0.153	0	0
Sulfur	0.349	0	0
$NaHCO_3$	0.214	-226	-0.484
$KClO_3$	0.235	-93.5	-0.220
		Total	-0.937

Products

Substance	Quantity Centimoles/g mix	Heat of Formation Kcal/mole	Kcal/g mix
CO_2	2.532	-94.052	-2.381
H_2O	1.655	-68.317	-1.131
SO_2	0.349	-70.94	-0.248
KCl	0.235	-104.35	-0.245
Na_2CO_3	0.107	-269.46	-0.288
N_2	0.153	0	0
		Total	-4.293

HEAT OF COMBUSTION = $-(-4.293 + 0.937) = 3.356 \frac{Kcal}{g\ mix}$

$\qquad 6046 \frac{BTU}{lb}$ This is the higher heating value since H_2O is assumed liquid

Lower Heating Value

$\qquad$ Vaporizing H_2O (0.01655) (10.52) = 0.174

$\qquad 3.182 \frac{Kcal}{g\ mix} = 5733 \frac{BTU}{lb}$

AT A RATE OF 8 GRENADES/MINUTE

Higher Heating = $(6046 \frac{BTU}{lb})$ $(\frac{8\ Grenades}{min.})$ $(\frac{11.5\ oz.}{Grenade})$ $(\frac{lb}{16\ oz})$ $(\frac{60\ min}{hr.})$ = $2.086 \times 10^6 \frac{BTU}{hr}$

HEAT OF COMBUSTION OF <u>VIOLET IV</u> (if dyes don't burn)

Reactants

Substance	Quantity Centimoles/g mix	Heat of Formation Kcal/mol	Kcal/g mix
Combustable C	2.425	0	0
Available H	2.413	0	0
Combined H_2O	0.341	-68.317	-0.233
Combined N_2	0.153	0	0
Sulfur	0.349	0	0
$NaHCO_3$	0.214	-226	-0.484
$KClO_3$	0.235	-93.5	-0.220
		Total	-0.937

Products

Substance	Quantity Centimoles/g mix	Heat of Formation Kcal/mol	Kcal/g mix
Carbon	2.425	0	0
Hydrogen	2.413	0	0
Water	0.448	-68.317	-0.306
SO_2	0.349	-70.94	-0.248
KCl	0.235	-104.35	-0.245
N_2	0.153	0	0
Na_2CO_3	0.107	-269.46	-0.288
CO_2	0.107	-94.052	-0.101
		Total	-1.188

Higher Heat $= 0.251 \frac{Kcal}{g} = 452.2 \frac{BTU}{lb}$

Lower Heat $= 0.204 \frac{Kcal}{g} = 367.3 \frac{BTU}{lb}$

HEAT RELEASE FROM 8 GRENADES/MIN.

$8 \frac{grenades}{min} = 345 \ lb/hr$

1) Smoke Dye Burning (from data pg. 6)

Higher Heating Value

$(345 \frac{lb}{hr}) \ (6046 \ \frac{BTU}{lb}) = 2.036 \times 10^6 \ \frac{BTU}{hr}$

Lower Heating Value

$(345 \frac{lb}{hr}) \ (5733 \frac{BTU}{lb}) = 1.978 \times 10^6 \ \frac{BTU}{hr}$

2) Smoke Dye Not Burning (from data pg. 7)

Higher Heating Value

$(345 \frac{lb}{hr}) \ (452.2 \frac{BTU}{lb}) = 1.560 \times 10^5 \ \frac{BTU}{hr}$

Lower Heating Value

$(345 \frac{lb}{hr}) \ (367.3 \frac{BTU}{lb}) = 1.267 \times 10^5 \ \frac{BTU}{hr}$

COMPOSITION OF <u>RED III</u> SMOKE GRENADE

Substance	Weight Fraction	Molecular Wt.	Moles/g mix
$C_{15}H_{11}NO_2$	0.357	237	15.063×10^{-4}
$C_6H_{10}O_5*$	0.063	162	3.889×10^{-4}
$NaHCO_3$	0.19	84	22.619×10^{-4}
$KClO_3$	0.28	122.6	22.838×10^{-4}
S	0.11	32.1	34.268×10^{-4}

Gaseous Products

CO_2 from combustion	2.493 centimoles/g mix
CO_2 from $NaHCO_3$	0.113 centimoles/g mix
H_2O from combustion	1.023 centimoles/g mix
H_2O from $NaHCO_3$	0.113 centimoles/g mix
SO_2	0.343 centimoles/g mix
N_2	0.075 centimoles/g mix
	4.160 centimoles/g mix

* For Dextrin $(C_6H_{10}O_5)_n \times H_2O$ assumed the water could be treated as an inert and be ignored.

Reactants

Substance	Quantity Centimoles/g mix	Heat of Formation Kcal/mol	Kcal/g mix
Carbon	2.493	0	0
Hydrogen	0.527	0	0
Water	0.496	-68.317	-0.233
N_2	0.075	0	0
Sulfur	0.343	0	0
$NaHCO_3$	0.226	-226	-0.511
$KClO_3$	0.228	-93.5	-0.213
		Total	-0.957

Products

Substance	Quantity Centimoles/g mix	Heat of Formation Kcal/mol	Kcal/g mix
CO_2	2.606	-94.052	-2.451
H_2O	1.136	-68.317	-0.776
SO_2	0.343	-70.94	-0.243
KCl	0.228	-104.35	-0.238
Na_2CO_3	0.226	-269.46	-0.609
		Total	-4.317

Higher Heat of Combustion = $3.36 \frac{Kcal}{g}$ = 6053 $\frac{BTU}{lb}$

Lower Heating Value = $3.24 \frac{Kcal}{g}$ = 5838 $\frac{BTU}{lb}$

COMBUSTION OF <u>RED III</u> (if dyes don't burn)

	Products		
	Quantity	Heat of Formation	
Substance	Centimole/g mix	Kcal/mol	Kcal/g mix
Carbon	2.493	0	0
Hydrogen	0.527	0	0
Water	0.609	-68.317	-0.416
SO_2	0.343	-70.94	-0.243
KCl	0.228	-104.35	-0.243
N_2	0.075	0	0
Na_2CO_3	0.226	-269.46	-0.609
CO_2	0.113	-94.052	-0.106
		Total	-1.612

Higher Heat of Combustion $= 0.655 \ \frac{Kcal}{g} = 1180 \ \frac{BTU}{lb}$

Lower Heat of Combustion $= 0.591 \ \frac{Kcal}{g} = 1065 \ \frac{BTU}{lb}$

HEAT RELEASED FROM 8 GRENADES/MIN.

1) Smoke Dye Burning (from data pg. 10)

Higher Heating Value

$$(345 \tfrac{lb}{hr}) (6053 \tfrac{BTU}{lb}) = 2.088 \times 10^6 \tfrac{BTU}{hr}$$

2) Smoke Dye Not Burning (from data pg. 11)

Higher Heating Value

$$(345) (1180) = 4.071 \times 10^5 \tfrac{BTU}{hr.}$$

Lower Heating Value

$$(345) (1065) = 3.674 \times 10^5 \tfrac{BTU}{hr.}$$

COMPOSITION OF GREEN IV SMOKE GRENADE

Substance	Weight Fraction	Molecular Wt.	Moles/g mix
$C_{28}H_{22}N_2O_2$	0.280	418.5	6.691×10^{-4}
$C_{24}H_{12}O_2$	0.042	332.3	1.264×10^{-4}
$C_{12}H_{10}O$	0.078	230.2	3.388×10^{-4}
$NaHCO_3$	0.226	84.0	26.905×10^{-4}
$KClO_3$	0.270	122.6	22.023×10^{-4}
S	0.104	32.1	32.399×10^{-4}

Gaseous Products

CO_2 from combustion	2.753 centimoles/g mix
CO_2 from $NaHCO_3$	0.135 centimoles/g mix
H_2O from combustion	0.981 centimoles/g mix
H_2O from $NaHCO_3$	0.135 centimoles/g mix
SO_2	0.324 centimoles/g mix
N_2	0.067 centimoles/g mix
	4.395 centimoles/g mix

Reactants

Substance	Quantity Centimoles/g mix	Heat of Formation Kcal/mol	Kcal/g mix
Combustable Carbon	2.753	0	0
Available Hydrogen	1.577	0	0
Combined Water	0.193	-68.317	-0.132
Sulfur	0.324	0	0
$NaHCO_3$	0.269	-226	-0.608
$KClO_3$	0.220	-93.5	-0.206
N_2	0.067	0	0
		Total	-.946

<u>Products</u>

Substance	Quantity Centimoles/g mix	Heat of Formation Kcal/mol	Kcal/g mix
CO_2	2.888	-94.052	-2.716
H_2O	1.116	-68.317	-0.762
SO_2	0.324	-70.94	-0.230
N_2	0.067	0	0
KCl	0.220	-104.35	-0.230
Na_2CO_3	0.135	-269.46	-0.364
		Total	-4.302

Higher Heating Value = $3.356 \frac{Kcal}{g\ mix}$ = $6041 \frac{BTU}{lb}$

Lower Heating Value = $3.239 \frac{Kcal}{g\ mix}$ = $5829 \frac{BTU}{lb}$

HEAT OF COMBUSTION OF <u>GREEN IV</u> (if dyes don't burn)

Reactants

Substance	Quantity Centimoles/g mix	Heat of Formation Kcal/mol	Kcal/g mix
Combustable Carbon	2.753	0	0
Available Hydrogen	1.577	0	0
Combined Water	0.193	-68.317	-0.132
Combined Nitrogen	0.067	0	0
Sulfur	0.324	0	0
$NaHCO_3$	0.269	-226	-0.608
$KClO_3$	0.220	-93.5	-0.206
		Total	-.946

Products

Substance	Quantity Centimoles/g mix	Heat of Formation Kcal/mol	Kcal/g mix
C	2.753	0	0
H	1.577	0	0
H_2O	0.328	-68.317	-0.224
N_2	0.067	0	0
SO_2	0.324	-70.94	-0.230
CO_2	0.135	-94.052	-0.127
Na_2CO_3	0.135	-269.46	-0.364
KCl	0.220	-104.35	-0.230
		Total	-1.175

Higher Heat of Combustion $= 0.229 \frac{Kcal}{g} = 412.6 \frac{BTU}{lb}$

Lower Heat of Combustion $= 0.194 \frac{Kcal}{g} = 349.5 \frac{BTU}{lb}$

HEAT RELEASE FROM 8 GRENADES/MIN

1) Smoke Dye Burning

   Higher Heating Value

   $(6041)(345) = 2.0841 \times 10^6 \frac{BTU}{hr}$

   Lower Heating Value

   $(5829)(345) = 2.0110 \times 10^6 \frac{BTU}{hr}$

2) Smoke Dye Not Burning

   Higher Heating Value

   $(412.6)(345) = 1.423 \times 10^5 \frac{BTU}{hr.}$

   Lower Heating Value

   $(349.5)(345) = 1.206 \times 10^5 \frac{BTU}{hr}$

MASS BALANCES AROUND FURNACE
Organics burn in furnace, Green IV

Grenades 8 lb/min.

Air 540 $\frac{scf}{min}$

Fuel Gas 50 $\frac{scf}{min}$

Furnace

Flue Gas 1800 scfm

Dilution Air x $\frac{scf}{min}$
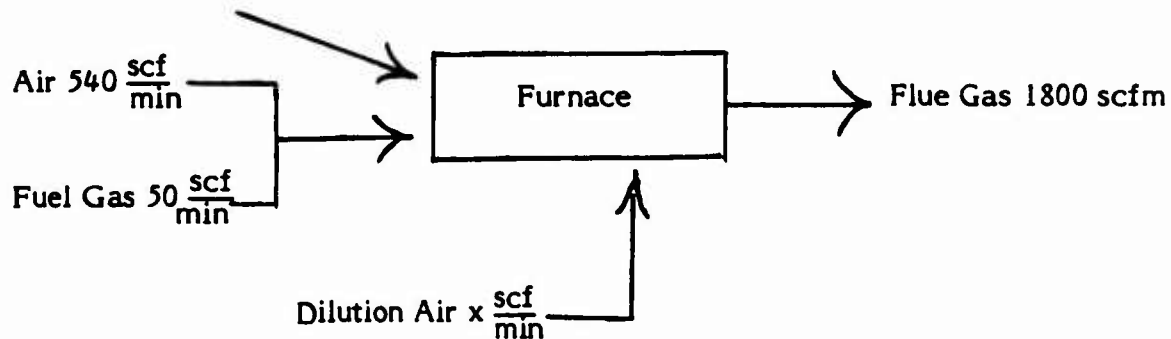
Input 60 F

Output 700 F

Gas

$$(50)\left(\frac{1}{379}\right) = .132 \frac{moles}{min}$$

Air

$$(540)\left(\frac{1}{379}\right) = 1.425 \frac{moles}{min.}$$

Grenades

$$\left(8 \frac{grenade}{min}\right)\left(11.4 \frac{scf}{grenade}\right)\left(\frac{1}{379}\right) = 0.24 \frac{moles}{min.}$$

Dilution Air

$$X\left(\frac{1}{379}\right) = \frac{x}{379} \frac{moles}{min.}$$

Flue Gas

$$1800\left(\frac{1}{379}\right) = 4.749 \frac{moles}{min.}$$

$$.132 + 1.425 + 0.24 + \frac{x}{379} = 4.749$$

$$x = 379 (2.952)$$

$$\underline{x = 1119 \ scf/min \ in \ Dilution \ Air}$$

If Organics Don't Burn Green VI

Grenade 8 lb/min

Air 540 $\frac{scf}{min}$

Fuel 50 $\frac{scf}{min}$

Furnace

Flue Gas 1800 scfm

Dilution Air x $\frac{scf}{min.}$
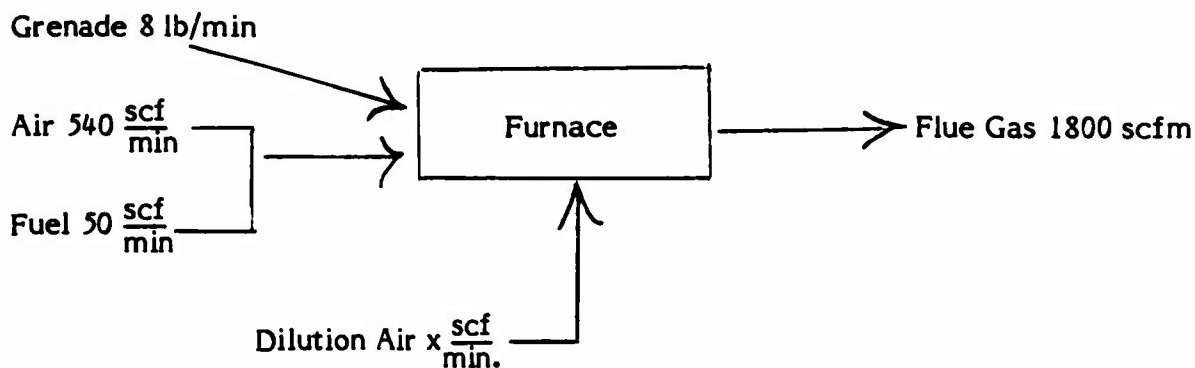
Grenade

$$(8 \; \frac{Grenades}{Min}) \; (1.53 \; \frac{scf}{grenade}) \; (\frac{1}{379}) = 0.0324 \; \frac{mol}{min}$$

Air

$1.425 \; \frac{moles}{min}$

Gas

$.132 \; \frac{moles}{min}$

Dilution Air

$\frac{x}{379} \; \frac{moles}{min.}$

Flue

$4.749 \; \frac{moles}{min.}$

$.132 + 1.425 + .0324 + \frac{X}{379} = 4.749$

X = 1197 scfm Dilution Air

EMISSIONS OF SULFUR FROM GRENADES

Yellow VI grenade

$0.265 \frac{centimoles}{g \, mix}$ SO_2 in gaseous products

$(2.65 \times 10^{-3} \frac{moles}{g \, mix})$ $(\frac{379 \, scf}{lb\text{-}mole})$ $(\frac{326.3g}{1 \, grenade})$ $(\frac{1 \, lb \, smoke}{454g\text{-}mole})$

$\underline{0.72}$ scf SO_2/grenade in Yellow VI

Violet IV grenade

$0.349 \frac{centimoles}{g \, mix}$ SO_2 in gaseous products

(3.49×10^{-3}) (379) $(\frac{326.3}{454}) = 0.95$ scf

$\underline{0.95}$ scf SO_2/grenade in Violet IV

Red III grenade

$0.343 \frac{centimoles}{g \, mix}$ SO_2 in gaseious products

(3.43×10^{-3}) (379) $(\frac{326.3}{454}) = 0.93$

$\underline{0.93}$ scf SO_2/grenade in Red III

Green IV Grenade

$0.324 \frac{centimoles}{g \, mix}$ SO_2 in gaseous products

(3.24×10^{-3}) (379) $(\frac{326.3}{454}) = 0.88$

$\underline{0.88}$ scf SO_2/grenade in Green IV

Tests have shown that 1/3 of the sulfur remains in the char of the grenade. This changes the emission volume.

Yellow VI

(2.65×10^{-3}) $(\frac{2}{3})$ (379) $(\frac{326.3}{454})$ = 0.48 scf

0.48 scf SO_2/grenade

Violet IV

(3.49×10^{-3}) $(\frac{2}{3})$ (379) $(\frac{326.3}{454})$ = 0.63 scf

0.63 scf SO_2/grenade

Red III

(3.43×10^{-3}) $(\frac{2}{3})$ (379) $(\frac{326.3}{454})$ = 0.62 scf

0.62 scf SO_2/grenade

Green IV

(3.24×10^{-3}) $(\frac{2}{3})$ (379) $(\frac{326.3}{454})$ = 0.59 scf

0.59 scf SO_2/grenade

APPENDIX II

SUPPORT DATA

APPENDIX II

SUPPORT DATA

II.1 SELECTION OF COLORED SMOKE

M18 smoke grenades filled with Green IV smoke mix were selected for the objective 1 tests because Green IV smoke mix more closely matches the BZ/pyromix in the heat of explosion and impact sensitivity then does the other smoke mixes (Yellow VI, Violet IV and Red III). Table II-1 compares some of the possibly relevant properties of sulfur-based smokes and BZ/pyromix.

The auto ignition temperature for all of the smokes is approximately 200 C. For BZ/pyromix, DTAs by Dow and Amcel suggest auto ignition temperatures of 145 C and 200 C, but Amcel reported a 10 second auto ignition temperature for BZ/pyromix of 390 C. (The possibility exists that this value was measured as Fahrenheit but erroneously reported as Centrigrade, as 390 F $\simeq$ 200 C.)

Burning rates for the smoke mixtures and for BZ/pyromix are quite different. The M18 smoke grenades have a burning time of about 60-90 seconds, while the BZ munitions have burning times more typically of 10-20 seconds.

Within the constraints, M18 grenades filled with Green IV smoke mix appear to be the best choice for simulating incineration of BZ munitions.

II.2 INERTING PROCEDURE

Composition of the inerting fluid, selected on the basis of the proposed inerting fluid for the demilitarization facility, was as follows:

Component	Composition, percent by weight
Water	99.99
Avirol III	0.01

The inerting procedure used for objective 1 tests was as follows:

(1) Soak the smoke grenades in the inerting solution for two hours in a vertical orientation with the tapes covering the vent holes removed.

TABLE II.1. COMPARISON OF EXPLOSIVE PROPERTIES OF COLORED SMOKES AND BZ/PYROMIX

Material	Calculated Heat of Explosion, cal/g		Impact Sensivity, cm Drop, 2 kg Mass, 50% Initiation		Volume of Products from Normal Functioning, scf	Volume of Products from Complete Combustion, scf
	Bicarbonate Undecomposed, Agent Solid	Bicarbonate Decomposed, Agent Vaporized	KClO$_3$ + Agent Mixture	Agent Only		
Yellow VI	218	132	112	30 – Dye 1 17 – Dye 2		
Green IV	294	227·	164	30 – Dye 1 17 – Dye 2 152 – Dye 3	2.29(b)	45.0(b,d)
Violet IV	313	254	>352	144 – Dye 1 218 – Dye 2		
Red III	305	243	>352	>352(a)		
BZ/Pyromix	254	190	43	119	1.4/6.7(c)	46.8/224(c,d)

(a) Dextrinated
(b) For one M18 Grenade
(c) Volume for M6/Volume for M138
(d) Including combustion air

(2) Remove the smoke grenades and allow the smoke grenades to air dry (drain), oriented vertically for 22-24 hours.

The smoke grenades were weighed before inerting and after drying.

II.3 DEACTIVATION FURNACE FLUE FLOW CORRECTION CURVE

The flow indicator for the flue flow leaving the deactivation furnace going to the afterburner used a pilot tube to measure the flow. The flow indicator requires correction. During testing on December 7, 1981 two velocity traverses were taken and the results are shown in Figure II.1. The curve in Figure II.1 can be used as a guide to the actual flue flow leaving the deactivation furnace (at 450 F).

II.4 BLOWER CALIBRATION CURVE

An inlet orifice was built and installed on the blower providing air to the natural gas burner on the deactivation furnace used during testing. Figure II.2 is the calibration curve for the inlet orifice. The curve was generated from the following equation giving cubic feet per minute.

$$V = 5.19 \, Cfd^2 \sqrt{iT/B}$$

where $f = \dfrac{1}{\sqrt{1-r^4}}$

r = ratio of orifice diameter to pipe diameter, d/D

d = diameter of the orifice in inches

i = the pressure drop in inches of water

B = pressure before orifice in inches Hg

T = Absolute temperature of air, R

C = orifice coefficient

D = pipe diameter in inches.

The values for the installed orifice are as follows:

d = 7.00 inches

C = 0.60

D = 8.0 inches.

The inlet orifice is shown in Figure II.3.

FIGURE II.1

FLOW FROM DEACT. FURNACE

INDICATED VS ACTUAL FLOW IN DUCT

LEGEND
□ = MEASURED BY BILL BAYTOS 12/7/81

ACFM AT 460F, -4 IN WATER

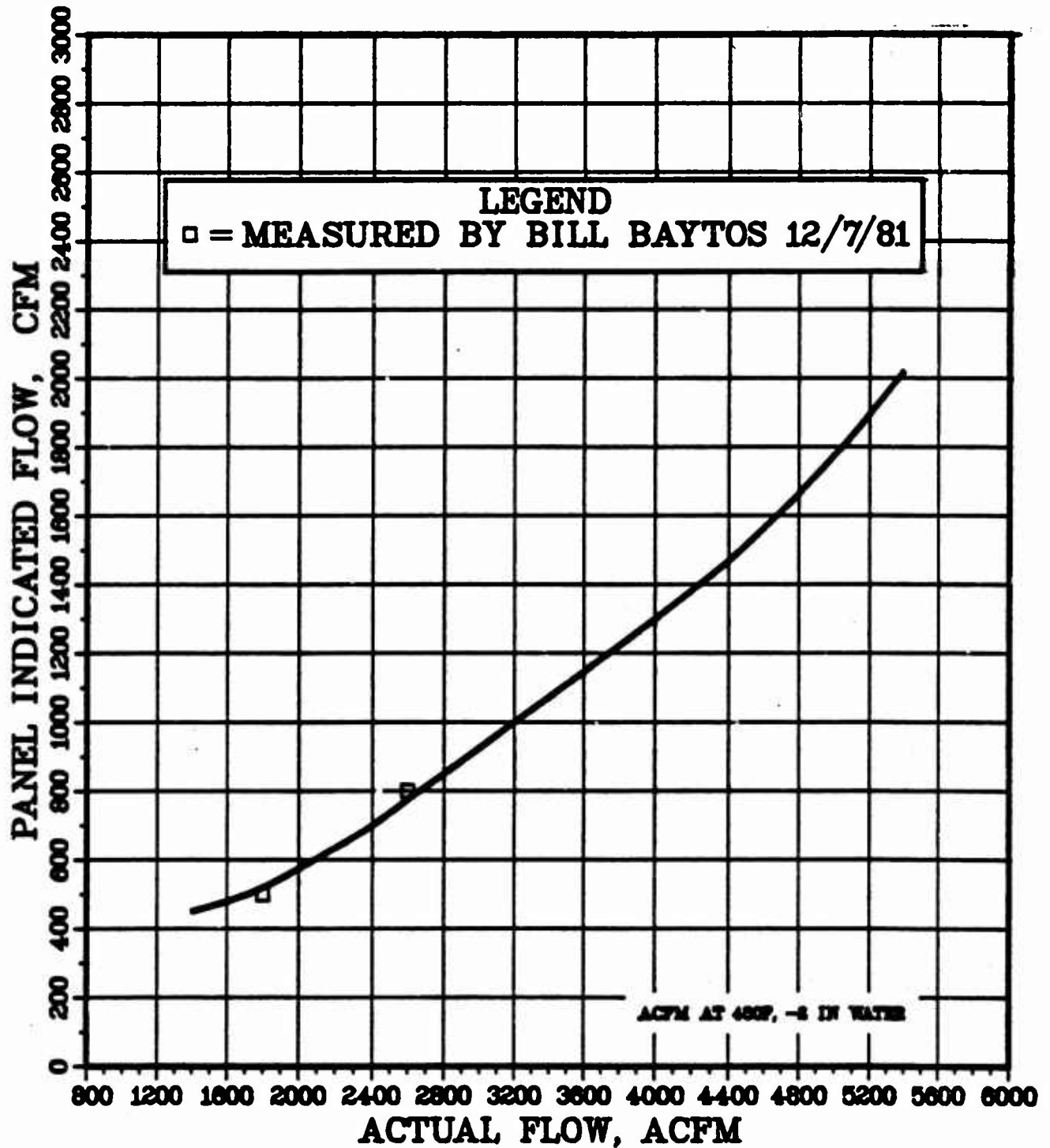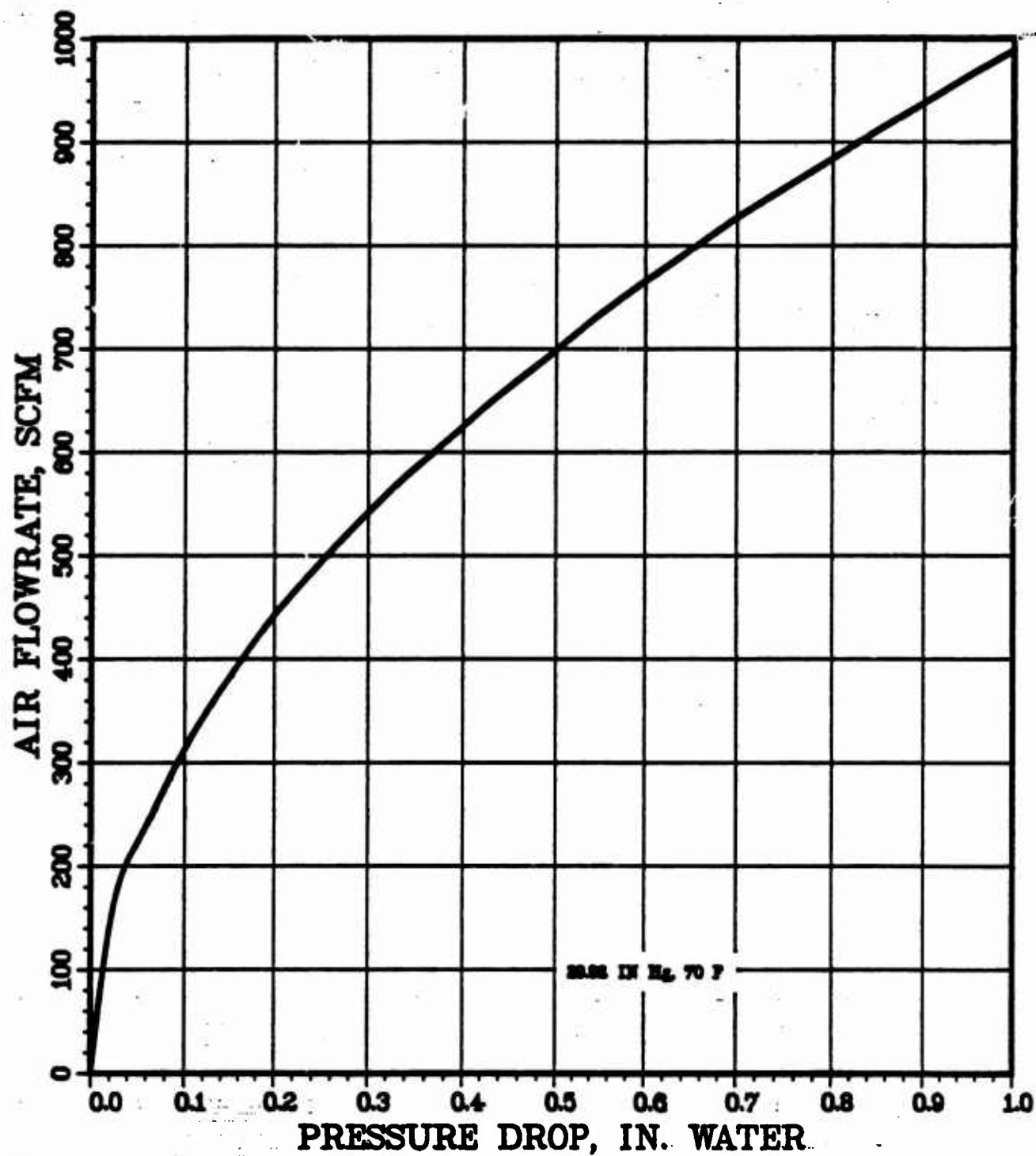PANEL INDICATED FLOW, CFM

ACTUAL FLOW, ACFM
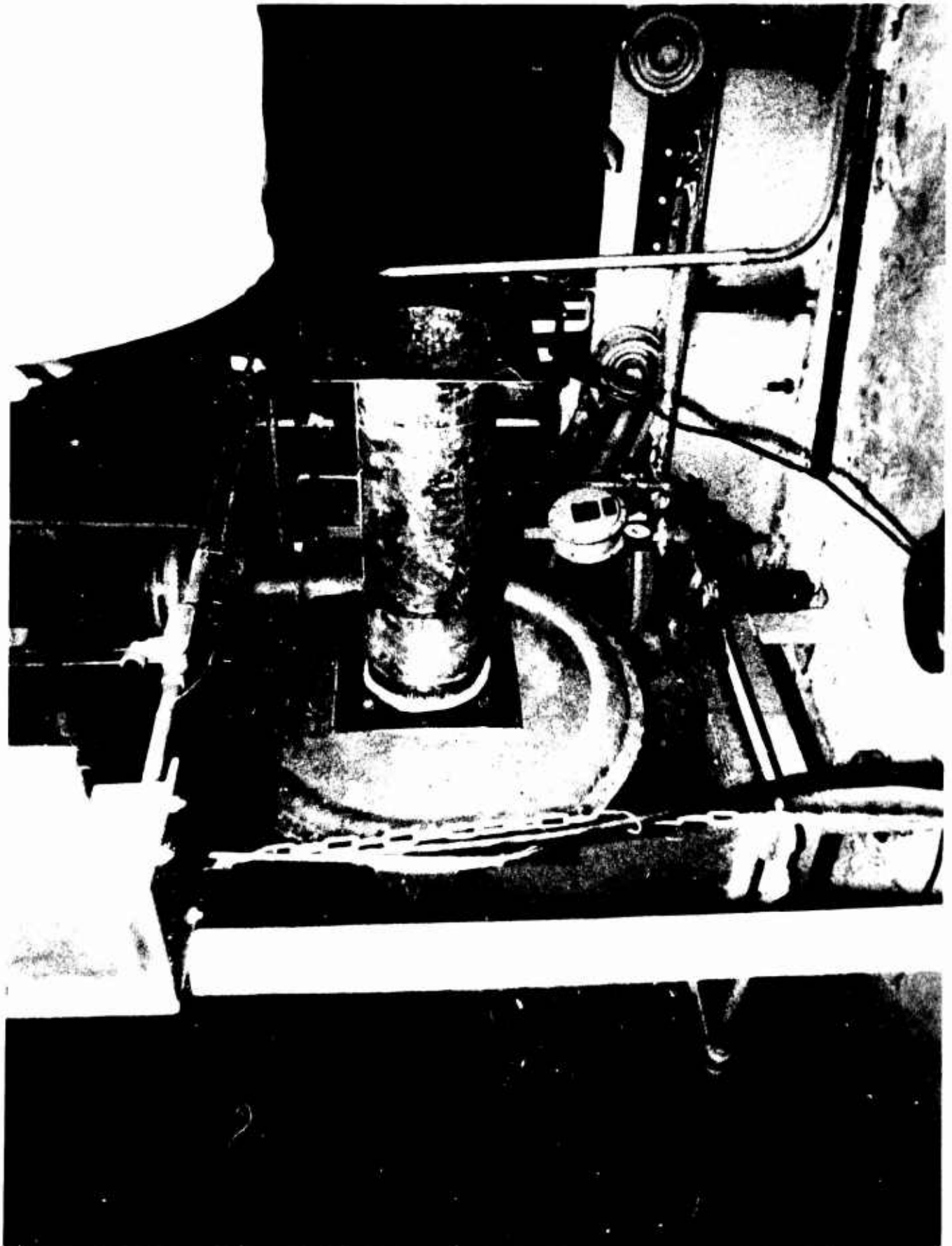
FIGURE II-2

BLOWER CALIBRATION CURVE

FIGURE II-3. INLET ORIFICE

II.5 ROTAMETER CORRECTION

A constant pressure variable area flow meter (rotameter) was installed in the natural gas line to the burner on the deactivation furnace to measure the natural gas flow. The rotameter was calibrated for air at 70 F and 14.7 psia. To correct the rotameter reading to the flowrate of natural gas, the equation below was used:

$$Q_2 = Q_1 \times (M_1 P_1 T_2 / M_2 P_2 T_1)^{\frac{1}{2}}$$

where   P = absolute pressure of gas

T = absolute temperature of gas

M = molecular weight of gas

Q = flowrate

and subscript 1 denotes gas conditions that the rotameter is calibrated

and subscript 2 denotes the gas conditions of gas being measured.

Q_2 can then be corrected to standard conditions.

II.6 FLOW STRAIGHTENERS

On a pretest visit to PBA's Incineration Complex in October 1981, it was determined that the flow in the duct between the quench and the venturi was cyclonic at the sampling ports. To eliminate cyclonic flow in the duct to permit valid sampling data, a flow straightener was designed and installed in the horizontal section of the duct between the two units. Its location can be seen in Figure II.4, and is indicated by an arrow.

The flow straightening device as designed and built consists of 3½ inch schedule 5, 316SS tubing, cut to 35-to 36-inch lengths, spot welded together and welded into a section of ducting. The flow straightener was then welded into the horizonal section of duct where a section of ducting was removed. The flow straightener is illustrated in Figure II.5.
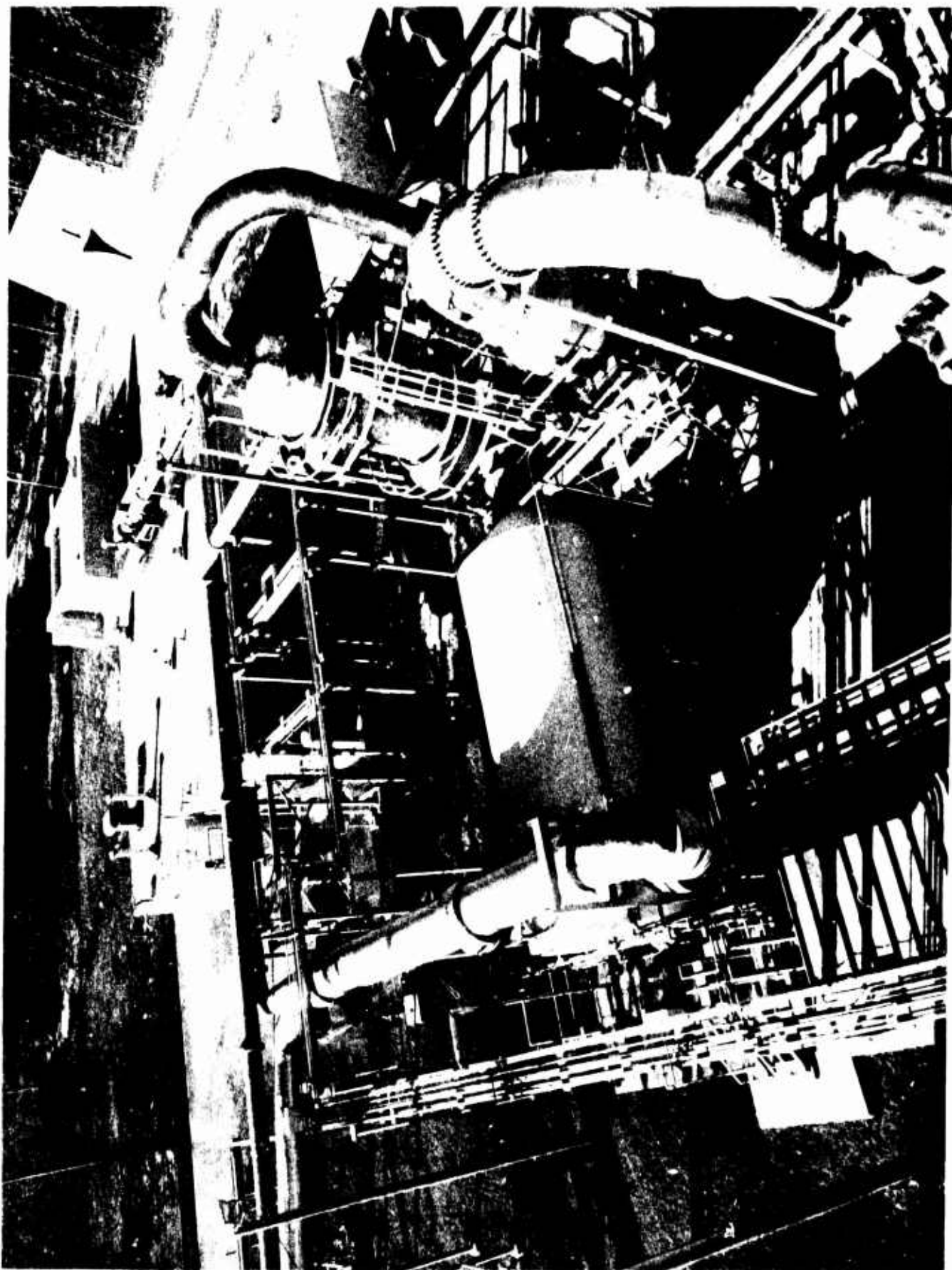
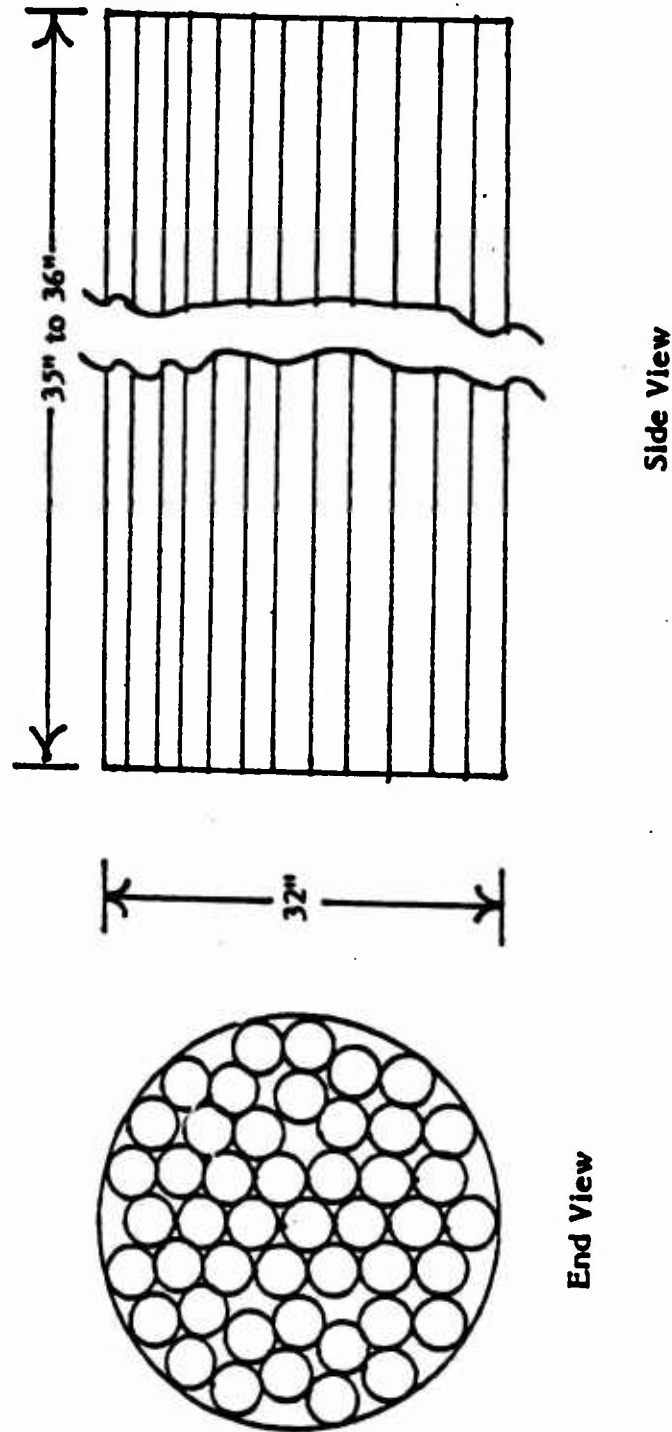FIGURE II-4. LOCATION OF FLOW STRAIGHTENER

35" to 36"

32"

Side View

End View

FIGURE II.5. FLOW STRAIGHTENER

II.7 HEAT AND MASS BALANCES

Mass Balance

The following is a mass balance over the system which consists of the deactivation furnace, afterburner, and stack. The natural gas and the airflow rates into the deactivation furnace are known and the flow rate from the deactivator is known. The gas compositions and the total gas flow rates are known at the stack and at the quench. We need to find the dilution air flow rate to the deactivation furnace, the natural gas and air flow rates to the afterburner and the dilution air flow rate between the quench and the stack.

	Flow Rate (scfm)		Volume Percent	
			At Quench	At Stack
Quench	4112.88	CO_2	5.5	1.97
Stack	12039.83	O_2	12.37	18.00
		N_2	82.13	80.03

Oxidation Reaction: $CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$
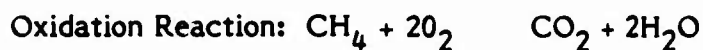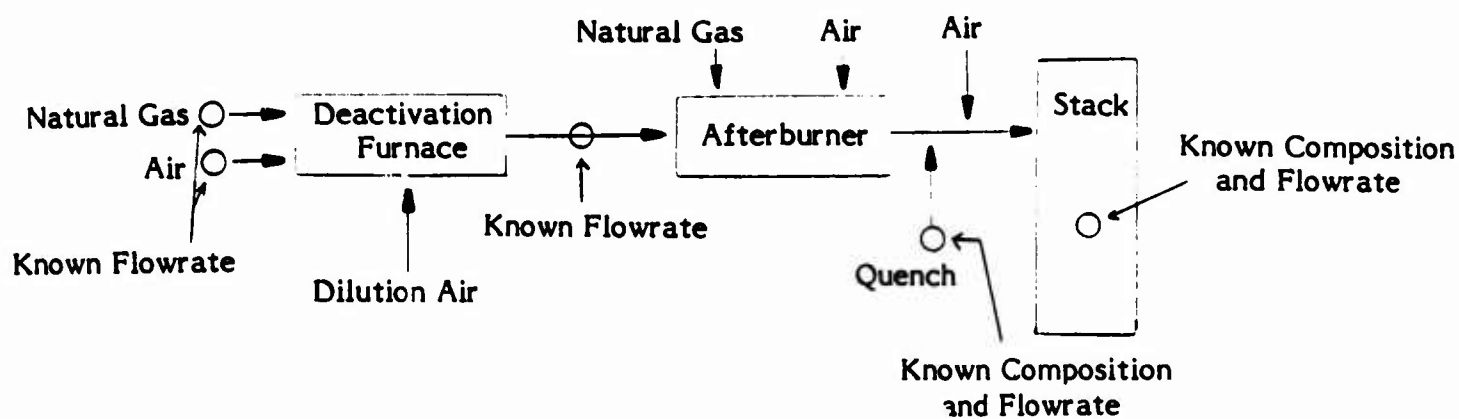
Gas flows to deactivation furnace burner:

Natural Gas	22.4 scfm
Air	593 scfm

Deactivation furnace burner exhaust:

N_2: 593 scfm Air x (.79N_2/1.0 Air) = 468.5 scfm N_2

O_2: (593 scfm Air) x (.21O_2/1.0 Air) - (2O_2/1CH_4) (22.4 CH_4 scfm) = 79.73 O_2

CO_2: (22.4 scfm CH_4) (1CO_2/1CH_4) = 22.4 scfm CO_2

Burner exhaust:

	Dry Basis (scfm)	Volume %
N_2	468.5	82.10
O_2	79.73	13.97
CO_2	22.4	3.93
Total	570.63	100

Total flow from deactivation furnace = 1900 scfm

Dilution Air = 1900 - 570.63 = 1329.37 scfm

Composition of flue gas to afterburner:

		Dry Basis (scfm)	Volume%
CO_2	22.4 + 0 =	22.74	1.18
N_2	468.5 scfm to Deact + (.79) (1329.37 scfm DilAir) =	1518.70	79.93
O_2	79.73 scfm to Deact +(.21) (1329.37 scfm DilAir) =	358.90	18.89
		1900	100

Also included with the flue gas to the afterburner is the unburned dye released from the mixture of colored smoke grenades fed into the system over a period of 2.5 minutes. The following table shows the composition of each dye:

Dye	Chemical	Wt. Fraction	MW	Grams per Grenade	# of Grenade
Yellow VI	$C_{17}H_{10}O$	.250	230.2	81.58	1
	$C_{24}H_{12}O_2$	.135	332.4	44.05	
Violet IV	$C_{14}H_{20}N_2O_2$	.336	248.3	109.64	6
	$C_{15}H_{11}NO_2$	.084	237	27.41	
Red III	$C_{15}H_{11}NO_2$	.357	237	116.49	4
	$C_6H_{10}O_5$	.063	162	20.56	
Green IV	$C_{28}H_{22}N_2O_2$	.280	418.5	91.36	9
	$C_{24}H_{12}O_2$	.042	332.3	13.71	

From this we can calculate the amount of C, O, and H in the flue gas due to the unburned dye.

			g-moles		
Chemical	Grams	g-moles	C	H	O
$C_{17}H_{10}O$	81.58	0.35	5.95	3.50	0.35
$C_{24}H_{12}O_2$	167.44	0.50	12.00	6.00	1.00
$C_{14}H_{20}N_2O_2$	657.84	2.65	37.10	53.00	5.30
$C_{15}H_{11}NO_2$	630.42	2.66	39.90	29.26	5.32
$C_6H_{10}O_5$	82.24	0.51	3.06	5.10	2.55
$C_{28}H_{22}N_2O_2$	822.24	1.96	54.88	43.12	3.92
			152.89	139.98	18.44

152.89 g moles/2.5 min = 61.16 g mole C/min = 0.135 lb moles C/min

139.98 g mole H/2.5 min = 0.123 lb moles H/min

18.44 g moles O/2.5 min = 0.016 lb moles O/min

From Dyes:

	(lb mole/min)	(scfm)
C	0.135	51.17
H	0.123	46.62
O	0.016	6.064

Exhaust from afterburner:

CO_2 5.5% (.055) (4112.88) = 226.21 scfm CO_2

CO_2 from Natural Gas Conversion

226.21 scfm - (51.17 scfm CO_2 from dyes + 22.4 CO_2 from Deact) =

152.62 scfm CO_2 from natural gas

Natural Gas to Afterburner = 152.62 scfm CH_4

N_2 from Afterburner 82.13%

(.8213) (4112.88 scfm at Quench) = 3377.91 scfm N_2

3377.91 - 1518.70N_2 from Deact = 1859.21 scfm N_2 to Afterburner

(1859.21 N_2 to Afterburner) (Air/.79 N_2) = 2353.43 scfm Air to Afterburner

O_2 to Afterburner: (2353.43 scfm Air) (.21O_2/Air) = 474.22 scfm

O_2 Balance around Afterburner:

$\qquad$ 474.22 scfm to afterburner

$\qquad$ +358.90 scfm from deactivator

$\qquad$ +(6.064) (½) scfm from dyes

$\qquad$ 836.12 scfm total O_2 fed to afterburner

$\qquad$ -2(152.64) $\quad$ O_2 Used by CH_4 to yield CO_2

$\qquad$ -51. $\qquad$ O_2 Used by C in dyes to yield CO_2

$\qquad$ -12 $\qquad$ O_2 used by H in dyes to yield $2H_2O$

$\qquad$ 467.84 scfm $\quad$ O_2 left in Quench

$\qquad$ O_2 Measured at Quench:

$\qquad$ (.1237) (4112.88) = 508.76 scfm

$\qquad$ Error = 508.76-467.84/508.76 x 100 = 8.04% Acceptable

Stack Gas:

$\quad$ Measured -

N_2: (.8003) (12039.83 scfm) = 9635.48 scfm N_2

$\quad$ 9635.48-3377.91 N_2 at Quench = 6257.57 scfm N_2 added

$\quad$ Air Flow Rate to Stack:

$\quad\quad$ (6257.57 scfm N_2) (Air/.79 N_2) = 7920.97 scfm Air added

O_2: Measured $\quad$ (.1800) (12039.83 scfm) = 2167.17 scfm O_2

2167.17 scfm O_2 - 508.76 scfm O_2 at Quench = 1658.41

$\quad$ (1658.41 scfm O_2) (Air/.21O_2) = 7897.19 scfm Air to Stack

$\quad$ Error = 7920.97-7897.19/7920.97 x 100 = 0.30%

Heat Balance

$\qquad$ The following sample calculation is a heat balance around the deactivation furnace. The heat that is transferred into the system via the grenades and the burner is known, the heat which comes out of the system in the scrap is approximated. We need to determine the heat loss through the stack gas and the heat transferred out through the surface of the retorts.

Heat in Btu/hr	Heat Out (Btu/hr)
Grenades 173,000	Stack Gas ?
Furnace Burner 1,344,000	Retorts ?
	Scrap, Char 56,000

Heat in Stack Gas

Flow Rate = 1900 scfm   ambient = 70 F

$$T = 440 \text{ F}$$
$$C_p = .25 \text{ Btu/lb m F}$$
$$MW = 29 \text{ lb/lb mole}$$
$$H = mC_p \Delta T$$

$$= \frac{1900 \text{ scf}}{\text{min}} \left| \frac{1 \text{ lb mole}}{379 \text{ scf}} \right| \frac{29 \text{ lb m}}{\text{lb mole}} \left| \frac{.25 \text{ Btu}}{\text{lb m - F}} \right| (440\text{-}70 \text{ F}) \left| \frac{60 \text{ min}}{1 \text{ hr}} \right.$$

$$= 806,873.35 \text{ Btu/hr.}$$

Overall Heat Balance

Heat In =	Heat Out
173,000 Btu/hr	56,000 Btu/hr
+1,344,000 Btu/hr	806,873 Btu/hr
———————	X Btu/hr
1,517,000 Btu/hr =	862873 Btu/hr + X

$$X = 654,127 \text{ Btu/hr Heat From Retorts}$$

Heat loss from retorts can be expressed:

$$Q = hA \Delta T = (h_c + h_r) A \Delta T$$

where

h_c = convective heat transfer coefficient

h_r = radiative heat transfer coefficient

A = Area of transfer = surface area of retort

ΔT = ambient temperature - skin temp.

Retort	T skin F	$(h_c + h_r)$Btu/hr ft^{2}F	A ft^2
1	638	6.11	47
2	540	5.13	47
3	425	4.23	47
4	480	4.77	47

Heat Lost from 1st Retort:

$$Q = \frac{6.11 \text{ Btu}}{\text{hr ft}^2 \text{ F}} \quad 47 \text{ ft}^2 \quad (638\text{-}70) \text{ F} = 163,113 \text{ Btu}$$

2nd Retort

$$Q = (5.13)(47)(540\text{-}70) = 113,322 \text{ Btu}$$

3rd Retort

$$Q = (4.23)(47)(425\text{-}70) = 70578 \text{ Btu}$$

4th Retort

$$Q = (4.77) (47) (480-70) = 91920 \text{ Btu}$$

Total Heat Loss   =   438,933 Btu

From Balance   =   654,127 Btu

Error = 654127-438933/654127 x 100 = 33%

II.8 PHOTOGRAPHS

The following photographs are included to aid in documentation of the test report. The list of photographs is as follows:

Figure II.6	Stack Sampling Port
Figure II.7	Stack Sampling Control Station
Figure II.8	Deactivation Furnace Building & Duct to Afterburner
Figure II.9	Feed Conveyor to Deactivation Furnace
Figure II.10	Incinerated M18 Smoke Grenade on Discharge Conveyor
Figure II.11	Sectioned M18 Smoke Grenade, No. 29[a]
Figure II.12	Sectioned M18 Smoke Grenade, No. 54
Figure II. 13	Sectioned M18 Smoke Grenade, No. 87
Figure II, 14	Sectioned M18 Smoke Grenade, From Test on 12/9/81
Figure II. 15	Sectioned M18 Smoke Grenade, From Test on 12/9/81

II.9 GRAPHS

The temperature versus time plots of the deactivation furnace temperatures are included to help in determining the impact of feeding eight grenades per minute into the furnace.

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a. For typical analysis of char sample, see Reference 1.
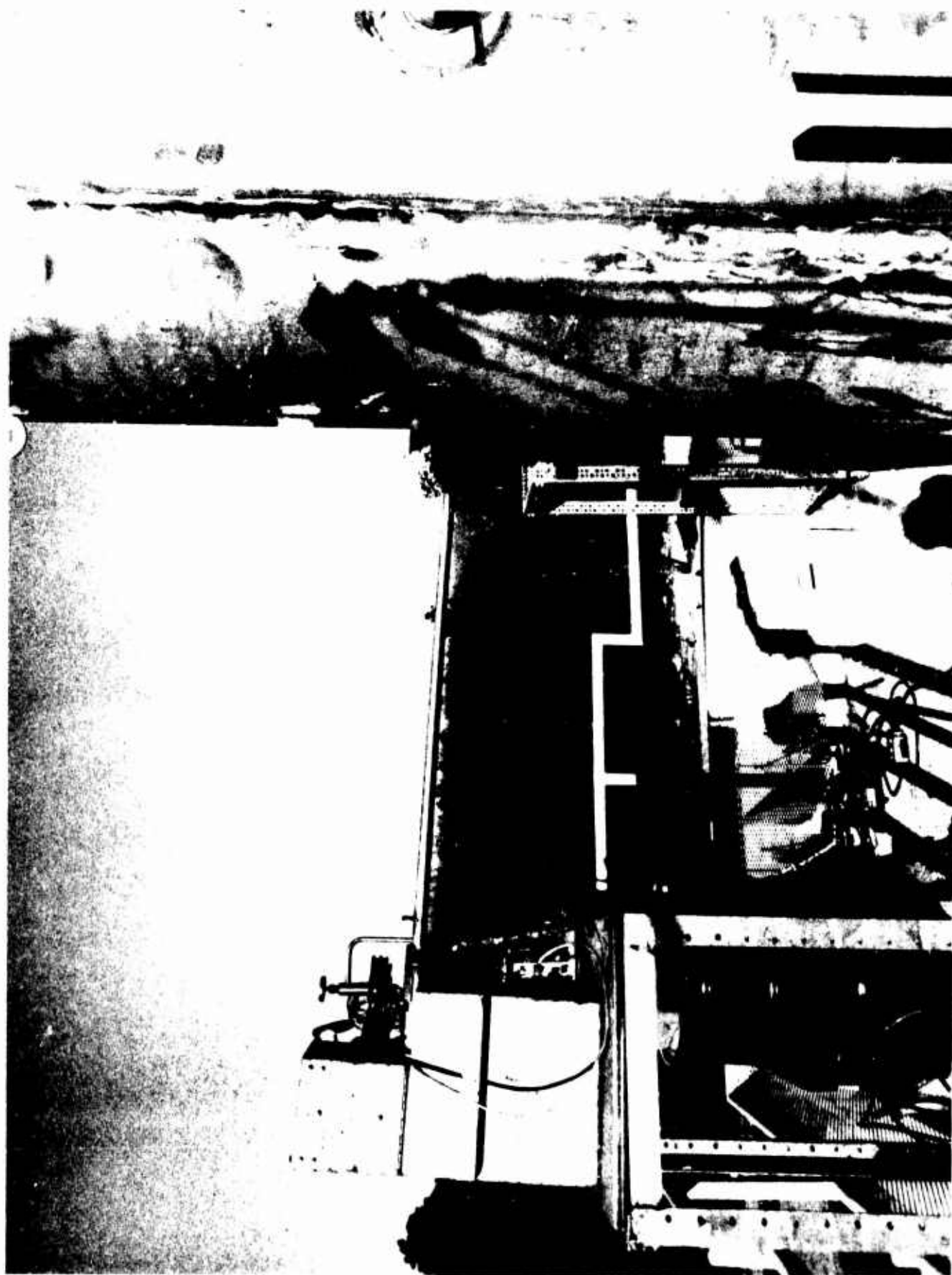
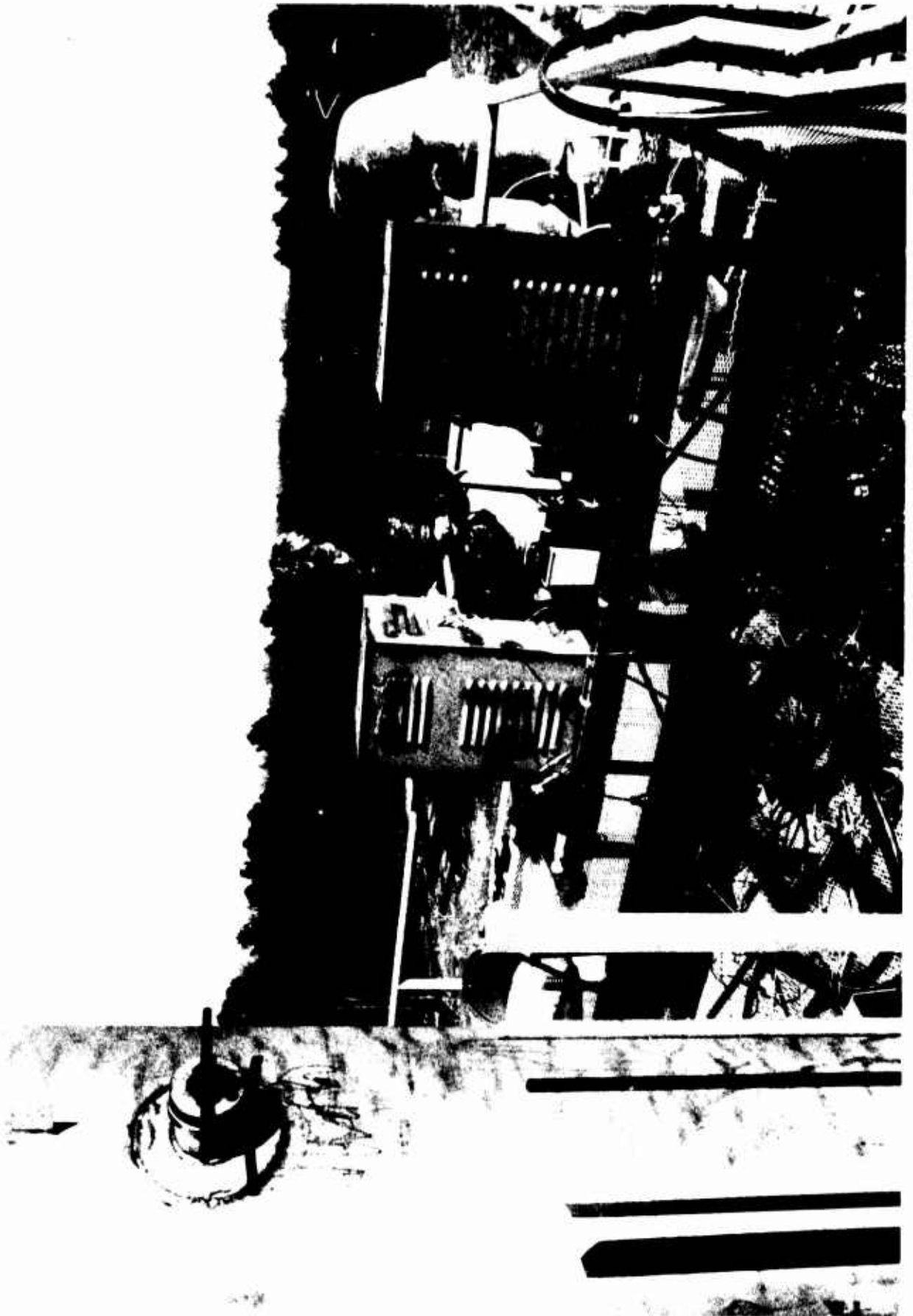FIGURE II-6. STACK SAMPLING PORT

FIGURE II-7. STACK SAMPLING CONTROL STATION

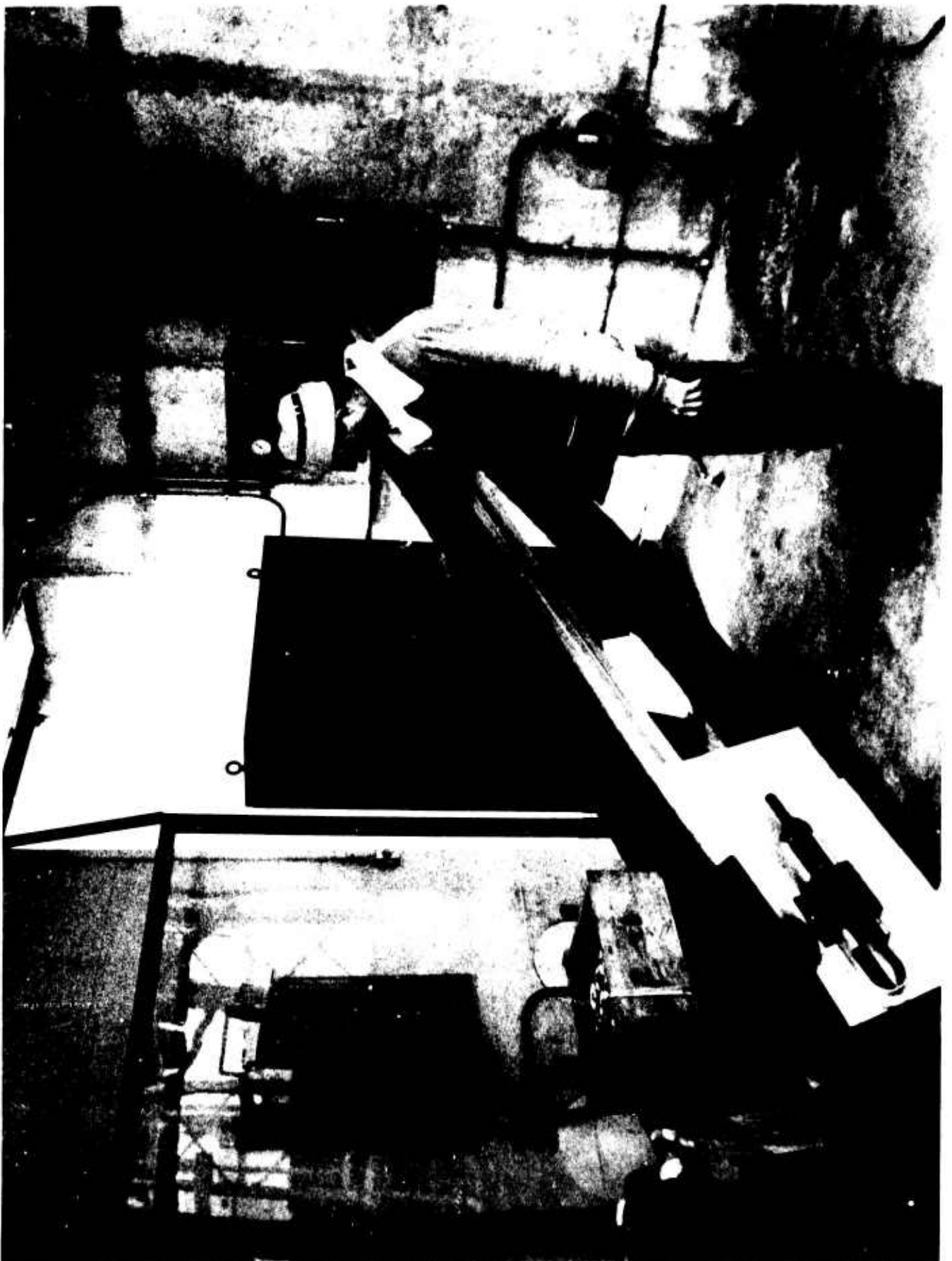FIGURE II-8. DEACTIVATION FURNACE BUILDING AND DUCT TO AFTERBURNER

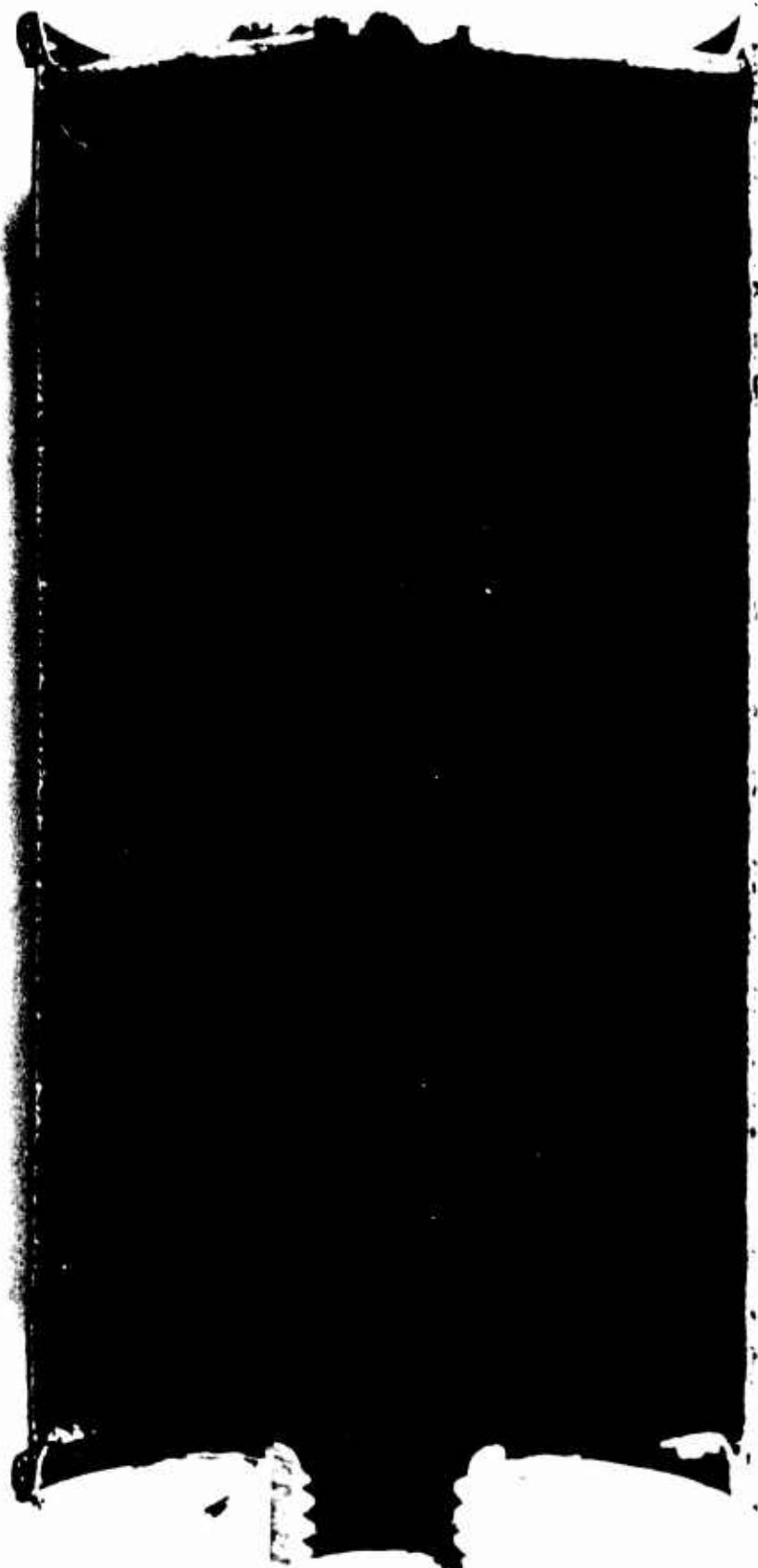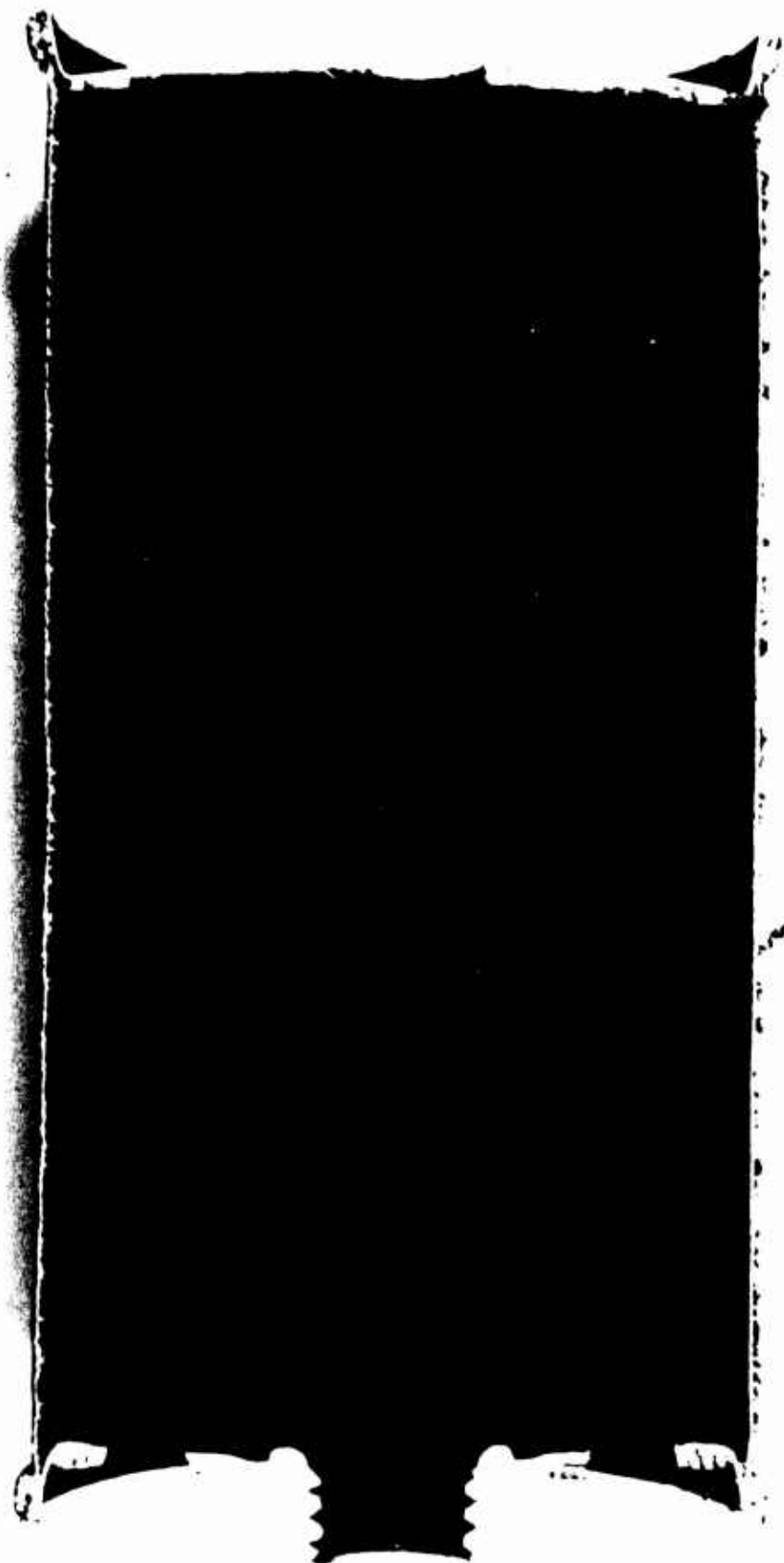FIGURE II-9. FEED CONVEYOR TO DEACTIVATION FURNACE

FIGURE II-10. INCINERATED M18 SMOKE GRENADE ON DISCHARGE CONVEYOR
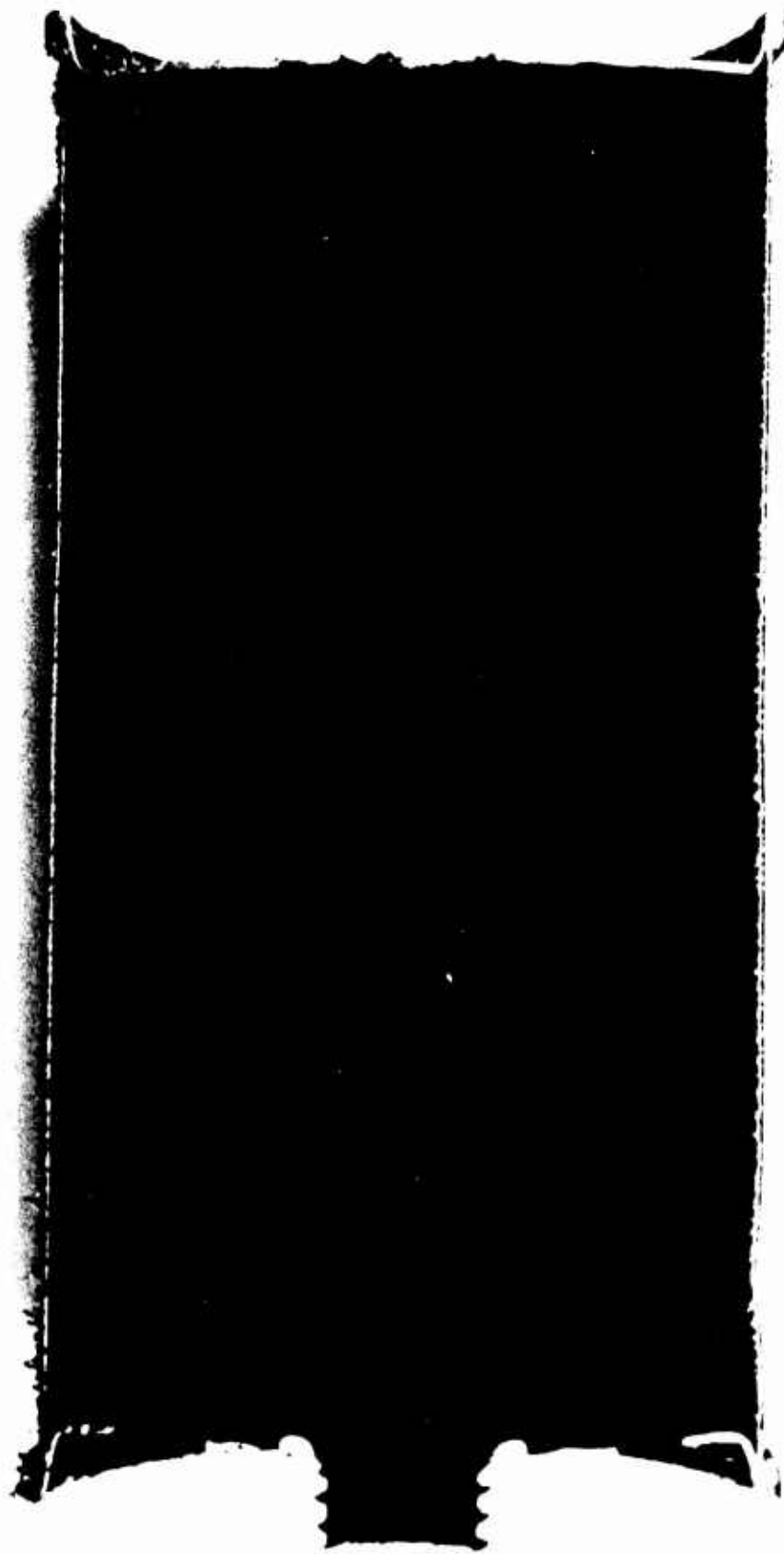
BATTELLE — COLUMBUS

29

FIGURE II-11. SECTIONED M18 SMOKE GRENADE, No. 29 a,b

BATTELLE – COLUMBUS

54

FIGURE II-12. SECTIONED M18 SMOKE GRENADE, NO. 54
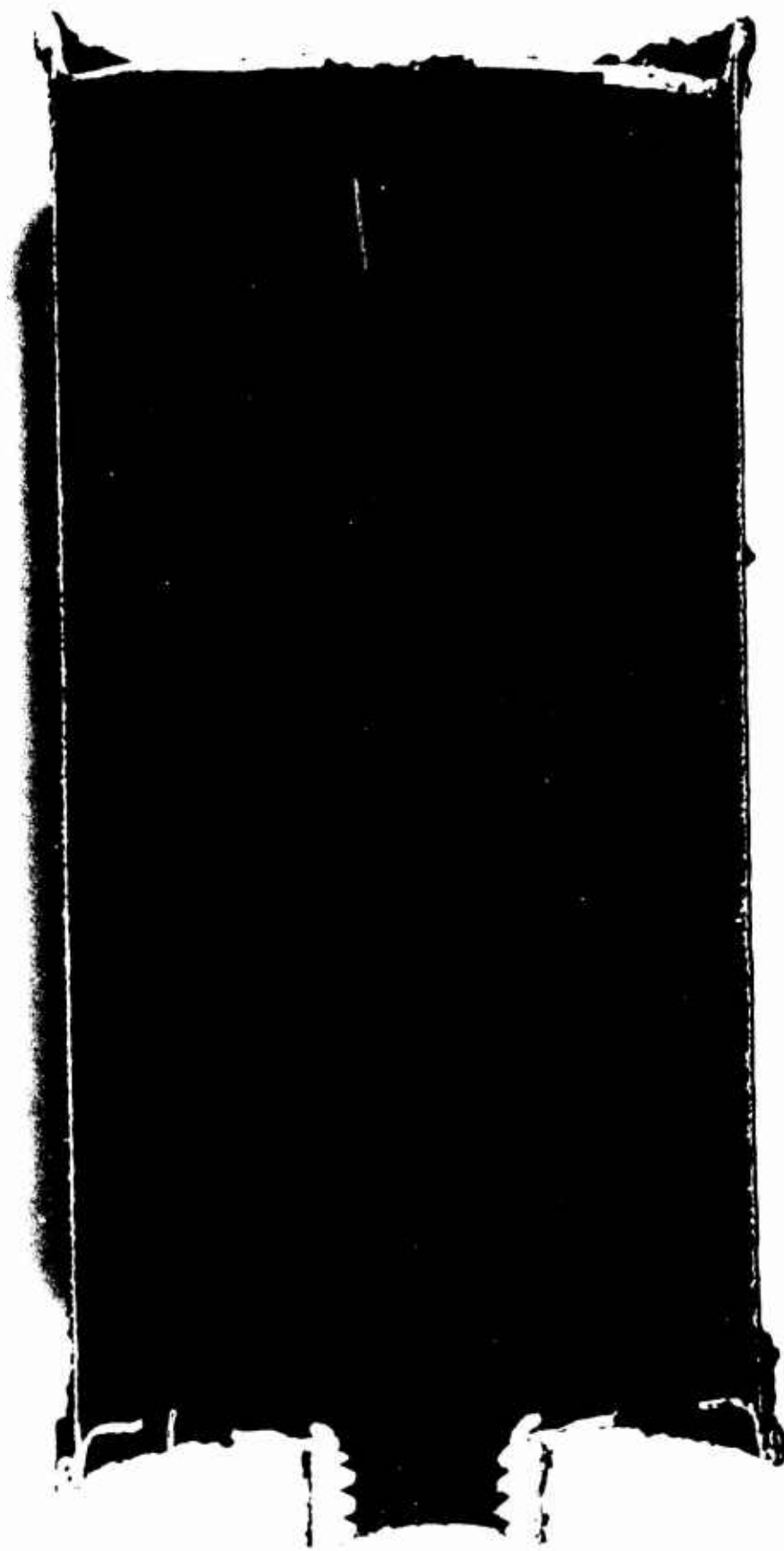
BATTELLE - COLUMBUS

FIGURE II-13. SECTIONED M18 SMOKE GRENADE, No. 87

BATTELLE — COLUMBUS

12/9/81

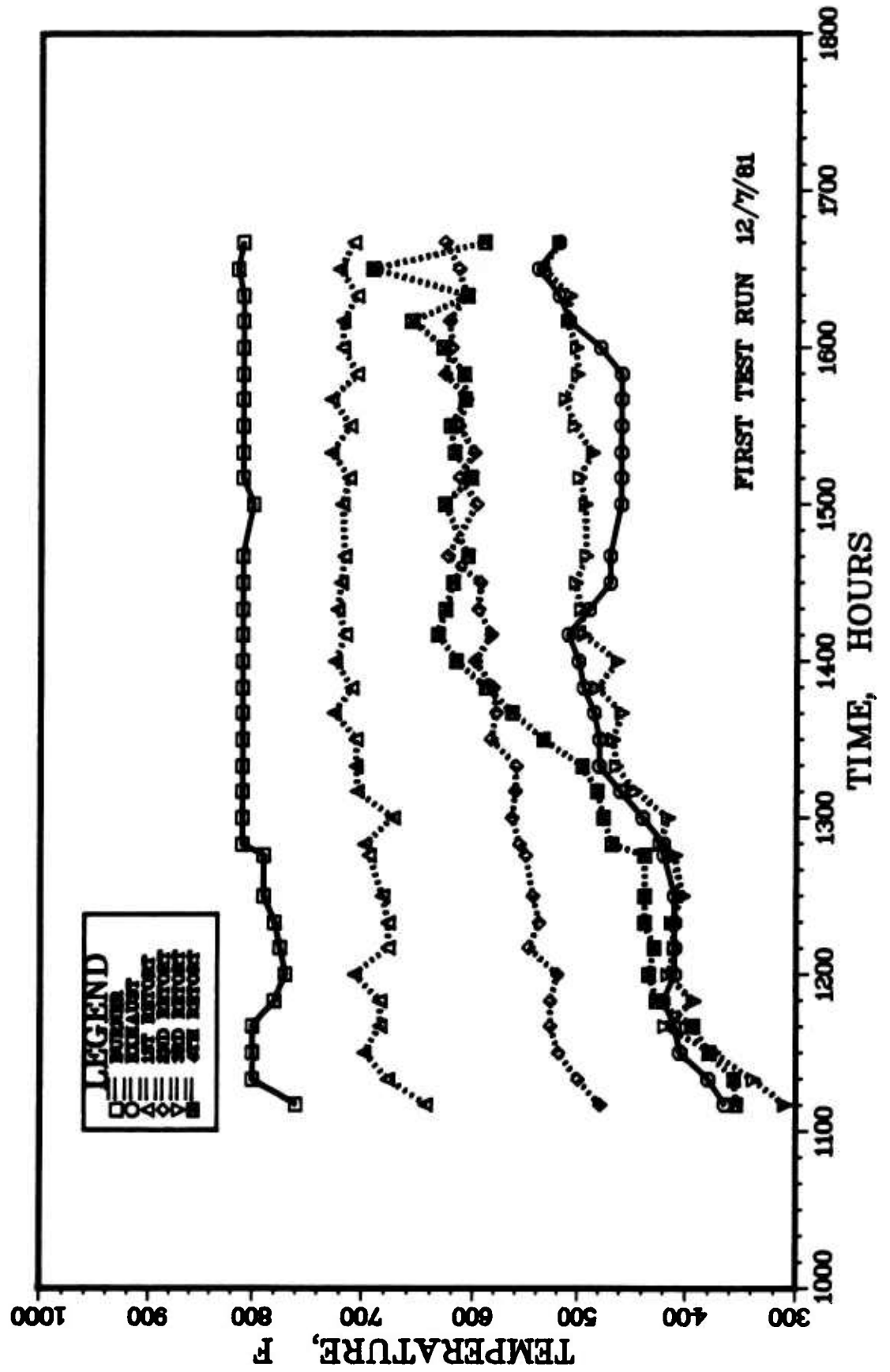FIGURE II-14. SECTIONED M18 SMOKE GRENADE, FROM TEST ON 12/9/81

FIGURE II-15. SECTIONED M18 SMOKE GRENADE, FROM TEST ON 12/9/81

TEMPERATURE VS TIME

FIRST TEST RUN   12/7/81

TIME, HOURS

TEMPERATURE VS TIME